DERIVING VALUE FROM HEALTH INFORMATION TECHNOLOGY: IMPACT OF PRIOR CLINICAL INFORMATION FROM AN ACCESSIBLE ELECTRONIC HEALTH RECORD ON LABORATORY AND RADIOLOGY TESTING IN A PEDIATRIC POPULATION

An article-style dissertation

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DEDICATION

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INTRODUCTION

BACKGROUND

Among advanced economies, the United States (US) spends more per capita on healthcare than any other country, yet has consistently poorer health outcomes (Bloomberg, 2013). Both per capita US spending and total healthcare spending as a percentage of gross domestic product remain the highest among industrialized nations (Fuchs, 2013). Health information technology (HIT) promises to help contain health care costs through improved efficiencies. One source of inefficiency that HIT promises to address is the overuse of laboratory or diagnostic imaging tests because prior test information was not accessible to the physician at the time of the patient encounter (Stair, 1998).

Substantial financial investments are being made by the federal government to promote the productive use of electronic health record (EHR) technology, a specific class of HIT that, among other things, collects and stores patient clinical diagnosis and treatment information (Hayrinen, 2008; Jha, 2009; ISO/TR 20514). This information can then be available to physicians electronically for use in providing subsequent diagnoses and care. Nevertheless, because patients commonly receive care across multiple health settings or health systems with different EHRs, providers may still lack access to a patient's prior test results and reorder tests which would not be necessary if the prior test results were accessible (Thomas, 2000; Gupta, 2010, Van Walraven, 2006). Improved information sharing, enabled through EHR technology and health information exchange, present a reasonable mechanism that may lower the incidence of inappropriate tests resulting from a lack of physician access to prior test information. This dissertation examines the impact of prior clinical information from an accessible EHR on problematic repeat medical testing.

Medical testing, including laboratory and medical imaging tests, is costly with an estimated 4.3 billion tests performed in the US annually at a cost of $65 billion (Alexander, 2012). Evidence exists that a substantial number of these tests may be redundant (Van Walraven, 1998; Bates, 1998b). What constitutes redundant testing varies widely across studies. The most common definitions of redundant testing are based upon test frequency and timing with a correlation demonstrated between repeat tests and redundancy (Van Walraven, 2003; Zhi, 2013). Both patient and physician factors have been shown to impact the frequency of redundant testing including: patient age, severity of illness, number of physicians placing orders, location of the patient assessment, test type and measurement criteria (Van Walraven, 2003). Redundant testing patterns may vary substantially by age suggesting a need for further research (Van Walraven, 2003). Understanding the mechanisms responsible for redundant testing may lead to lower rates of redundant testing. This can lower the burden on children, including the physical and mental impact of testing; improve patient care; and potentially lower the cost of care.

The timing of this research is important. Under the Affordable Care Act (ACA), the Federal government introduced Accountable Care Organizations (ACOs) as an economic model designed to better align health care payments for services with efforts to improve care quality while constraining the total cost of care (HHS-CMS, 2011a,b). Under the accountable care model, healthcare systems are generally "attributed" a set of patients that consume resources both inside and outside that particular healthcare system making up a patient's total cost of care. ACOs are then held at least partially responsible for containing both the healthcare costs incurred by physicians and patients and the total patient costs paid for by the payer, while maintaining care quality. Economic incentives are realized by ACOs when they meet performance standards regarding both the quality and the cost of care. Likewise, penalties are also incurred for

failure to achieve minimal thresholds of cost constraint and process and end-state outcomes. Under this new model, the ACO has direct responsibility for influencing both (1) the consumption of health services and (2) administrative costs of delivering care to a customer population (Gold, 2011; CMS, 2011). Health information technology can play an important role in helping health care organizations, including health systems and hospitals, achieve these goals.

THE IMPACT OF HIT ON EFFICIENCY IN CARE DELIVERY

Understanding the economic benefits derived from HIT is a complex undertaking. The Institute for Healthcare Improvement (IHI) encapsulated the goals of healthcare improvement in the so-called "Triple Aim" objectives, including an emphasis on improving the efficiency of the health system. The three-fold emphasis includes (1) improving health of the defined population (2) enhancing the patient care experience and (3) reducing or at least controlling the per capita costs of care (Berwick, 2008)

HIT investment, including the deployment of electronic health record technology, is seen as a critical component of achieving the Triple Aim objectives. By Executive Order in 2004, the George W. Bush administration established the Office of the National Coordinator for Health Information Technology (ONCHIT) as a Department of Health and Human Services. Passage of the American Recovery and Reinvestment Act (ARRA) and the related Health Information Technology Economic and Clinical Health (HITECH) Act in 2009 codified the position of national coordinator into law and provided $2 billion to fund the ONCHIT and $19.2B to fund the EHR incentive program. Beginning in 2011, Medicare and Medicaid now provide financial incentives to hospitals and physicians who can demonstrate a level of "meaningful use" of certified electronic health record technology (HHS-ONCHIT, 2012). The Congressional Budget Office is projecting at least a doubling of adoption rates of electronic health records by physicians and

hospitals by 2019 to 90% and 70% respectively (Sunshine, 2009). At these adoption levels, potential HIT-enabled efficiency savings was estimated at $77B annually across both inpatient and primary care (Hillestad, 2005) – suggesting the potential for full cost recovery of technology investments over time.

Early evidence from studies that looked at HIT support these policy efforts. Results of these studies were often favorable with demonstrated improvements in guideline compliance, enhanced monitoring, lower medication error rates, and improved economic efficiency through decreased utilization rates. However, several researchers have noted that early analysis was based primarily upon the results of 4 "benchmark" institutions (Linder, 2007; Poon, 2010; Chaudhry, 2006). Despite their success, these "homegrown" systems were unlikely options for most institutions that would deploy EHR technology and had limited generalizability (Chaudhry, 2006).

In 2007, the Agency for Healthcare Research and Quality (AHRQ) released an evidence report reviewing the results of 256 research studies to date addressing the costs and benefits of HIT (Shekelle, 2006). While the report concluded optimistically that HIT would assist in a "dramatic transformation in the delivery of healthcare, making it safer, more effective and more efficient", the authors also noted significant limitations in the "quality, quantity and generalizability of studies". Of the 256 studies, 15 were noted as either random or controlled clinical trials, with all of the 15 studies coming from benchmark institutions (Riegenstrief, Brigham and Womens, Intermountain Healthcare, Kaiser, Vanderbilt and the VA). The results were considered "highly context specific", limiting overall generalizability, given that these systems were unique and not commercially available. Though all predicted savings from HIT deployment, studies of the economic value were limited to nine studies – using multiple methods and differing assumptions – to arrive at their conclusions. A specific lack of cost studies was cited among HIT deployments in pediatric hospitals. Despite the limited evidence of cost

savings in pediatric hospitals, the report was “optimistic” regarding potential economic benefits to pediatric hospitals from investments in HIT (Shekelle, 2006).

Early national studies. Two important national studies followed the AHRQ report and highlighted the challenge of measuring efficiency gains from HIT. Himmelstein (2010) looked at the relationship between hospital “computerization” and the costs and quality of care in a national study published in 2010. This study involved the national selection of a diverse sample of hospitals. The EHR construct was defined as “computerization” and was measured as a proportion of the number of fully implemented EHR functions for which data were available. The 21-24 functions studied were grouped into three sub-scores or categories representing clinical, patient-related administration and other administration capabilities. In addition to looking at quality, a cost construct was also included in the analysis to assess the impact of EHR deployment on hospital administrative costs. The measurement applied was a proportion of the administrative costs of the hospital as a share of total costs. Increased computerization was associated with a faster increase in administrative costs. There was no evidence as well of a lagged effect between investment in technology and lower future costs, suggesting that technology investments increased the underlying administrative costs associated with delivering care (Himmelstein, 2010).

A second national study was published in 2010 that evaluated whether or not EHR adoption in hospitals was associated with better performance on a number of quality and efficiency measures (DesRoches, 2010). In this study, the EHR construct was broken into three tiers and scored based upon adoption level: comprehensive, basic or no EHR adoption. Information on specific functions – clinical decision support (CDS) and computerized physician order entry (CPOE) – were also captured for analysis purposes. The cost or efficiency construct included several measurements: risk-adjusted length of stay, risk-adjusted 30-day readmit, risk-adjusted inpatient costs and

observed to expected costs (measured as a ratio) adjusted for case mix, hospital mission and location. Data for cost analysis was drawn from the 2006 Medicare Provider Analysis and Review (MEDPAR) information (HHS-CMS, 2014b). As part of the study, an analysis was conducted on efficiency measures, using multivariate analysis to adjust for hospital characteristics. Overall, no association was identified between EHR adoption and length of stay or readmits. When examining pneumonia patients, hospitals with an EHR had a hospital length of stay (LOS) that was 0.5 days shorter ($p<.003$). No significant cost differences were noted between EHR and non-EHR hospitals ($p=0.22$). No significant differences were noted as well in analyzing risk-adjusted cost ratios for any of the three conditions. When adjusting for covariates, no significant associations were noted. Similar analysis was conducted on the association between two specific functions, CDS and CPOE, and improvements in quality and efficiency measures. These specific functions were associated with marginally better performance on each of the quality metrics (DesRoches, 2010).

Four more recent systematic reviews addressed both economic evaluation methods and cost outcomes. Gallego (2010) conducted a systematic review summarizing cost and benefit indicators in economic evaluations (n=24 studies). Bassi (2013) summarized economic indicators as well as the underlying economic methods used in health information economic evaluations (n=42 studies). Black (2011) reviewed the impact of selected e-health functionality on benefits and costs from 1997-2010 (n=53 studies). Finally, Buntin (2011) updated the earlier work by Chaudhry looking at specific economic outcomes associated with the deployment and use of HIT (n=154 studies).

Regarding cost outcomes from investment in health technology, Buntin reported that 92% of the recent articles published on HIT reached positive conclusions regarding one or more aspects of care. Gallego found that prospective economic evaluations demonstrated that annual benefits were 76.5% of first year costs and >300% of annual

costs, suggesting a rapid capital-recovering process. Annual benefits measured varied by study type. While both results are optimistic, some significant limitations exist in the methods applied. Both reviews acknowledged the impact of publication bias that significantly underreports neutral or poor economic results. Also, neither study followed a more traditional meta-analysis approach that provides corrected statistical measures for evaluating aggregated study results, including understanding the estimated aggregate impact of findings.

Black's findings were more inconclusive noting only anecdotal evidence of the benefits of EHRs and CPOE on organizational or individual physician efficiency. Stronger positive results were found for ePrescribing, including improved efficiency and patient outcomes. CDS's were cited as a source of behavior modification but only weak evidence was referenced for its impact on care quality (Black, 2011).

A separate review of the results of ten recent individual studies was mixed (Jones, 2011; Lee, 2013; Connelly, 2012; Dowding, 2012; Teufel, 2010, 2012; Appari, 2012; Furukawa, 2010, 2011; Zlabek, 2009) . Improvements were noted as statistically significant (due to sample size) but the magnitude was often small (Lee, 2013; Connelly, 2012; Dowding, 2012). The two pediatric hospital studies looking at hospital electronic medical record use and cost of inpatient pediatric care found that CPOE usage had no impact on cost of care (Teufel, 2010). The second study used a four-staged classification for EHR (Stage 0: no automation – Stage 3: advanced EMR automation) by hospital that detected a seven percent increase in cost among more advanced EHR users (Teufel, 2012).

Categorizing the effect of EHR use on cost outcomes and efficiency. Based upon the literature search conducted, three broad categories of potential cost outcomes through the use of HIT were identified. The first category includes the delivery of functionality that lowers the cost of delivering hospital-based care. This includes

lowering the variable cost of service delivery per unit of care through functionality that simplifies the nature and length of the service provided (Connelly, 2011; Lee, 2013; Furukawa, 2010; Teufel, 2012). It also includes renegotiating the price of labor or contracted services used to offer care (Furukawa, 2010) or better leveraging a fixed-cost infrastructure to capture productivity gains through increased scale. Chaudhry (2006) cites reductions in clinician time spent as one of the primary cost outcomes of the introduction of HIT. Menachemi and Collum cite reduced staff resources devoted to patient management, decreased transcription costs and costs related to chart pulls (Menachami, 2011).

The second is the delivery of functionality that alters physician behavior that lowers physician utilization of care, primarily through automating and informing the clinician order process using CPOE or medication management systems at the point of care. Such benefits are important from both a payer and health system perspective. Benefits can be realized through accessibility of prior clinical knowledge available in medical records to inform clinicians regarding patient care. These cost outcomes measure the elimination of errors or waste in the system as a result of unnecessary or redundant activities at the point of care. Strong evidence from multiple studies demonstrates these technologies can lower physician demand for lab and radiology tests at the point of care, with absolute decreases ranging from 8.5 to 24.0% (Chaudhry, 2006). More recently, Zlabel (2011) found significant reductions in ordering of lab tests and radiology exams per week per hospitalization, as well as significantly lower monthly transcription costs at one site. Connelly (2012) cites lower labs and prescriptions orders for heart failure patients in the emergency department. While the results in this category are generally positive, one national study on hospitals that care for children noted no significant change in utilization based upon CPOE use (Tuefel, 2010).

The third category is the delivery of functionality that enables better physician or patient decision making regarding care that then leads to lower future consumption of healthcare services from a population perspective. This category measures an intervention's ability to lower demand for future health services while maintaining health outcomes. This category may include maintaining healthcare consumption levels while improving health outcomes. The category can also include increasing short-term consumption, while increasing patient health outcomes at a more rapid pace in the long run, all with a goal to lower total cost of care over the patient's life. Arguably this third category could be viewed as a subset of category two though the emphasis here is on the long-term benefits of improved care and its impact on overall total patient cost of care from a population perspective. Decision support capabilities that inform the clinician and impact both present and future decisions regarding patient consumption of services, are designed in part to meet this cost objective. The presence of an EHR has been shown to impact readmission rates, impacting future service demand (Lee, 2013; Jones, 2011; Connelly , 2006; DesRoches, 2010). Dowding cites the benefits of an EHR on reducing hospital-acquired pressure ulcers that introduce future health complications requiring care (Dowding, 2012). Other examples include the potential impact of disease prevention, chronic disease management or care coordination programs on future demand for services (Katz, 2012; Auger 2013).

Of the three potential benefits associated with electronic health record use, this dissertation focuses on the second cost objective, lowering cost and improving care quality by studying impact that the presence of an accessible health record has on test repetition levels across a patient population. More efficient use of medical testing across a patient population could lower per patient spending over time, an important measure in accountable care programs, and reduce future demand for treatment through improved care quality.

TEST REPETITION IN MEDICINE

Testing in medicine has several purposes including screening populations to identify health problems or the potential for health problems; supporting the diagnosis of illness or measure the progression of disease in a patient; and monitoring the impact of treatment on the human body in general and on the progress of the disease itself (Van Walraven, 1998).

Given the dynamic nature of a patient's health state and the progressive nature of disease, repetition by clinicians of the same or similar tests with a given patient is common (Bates, 1998; Van Walraven, 1998). Repeat testing occurs for a number of reasons including: a particular test requires multiple instances to obtain useful information, a particular disease or treatment requires multiple results to obtain a clear understanding of disease progression or the impact of a health intervention or an initial test result is unclear or inconclusive requiring a repeat test. Known risk factors that may influence the level of repetitive screening, diagnosis or treatment testing include age, sex, race, disease type/severity, purpose of the test, test type, presence of comorbidities particularly chronic conditions, the accuracy of the test itself, the acute or chronic nature of the condition, location of care and passage of time (Van Walraven, 2003; Zhi, 2013).

Not all repeat tests are necessary or appropriate for care resulting in both overtesting and undertesting. Inappropriate testing may result from failing to administer either index or repetitive tests when such tests are warranted, for screening, diagnosis or treatment purposes (undertesting or missing tests). Inappropriate testing may also result from administering index or repeat tests that are not required for necessary or appropriate care (often noted as redundant or excess testing) (Zhi, 2013).

Undertesting occurs when no testing is performed despite the presence of one or more indicators identifed in Table 1. Undertesting may result in substandard patient care by failing to detect or diagnose the presence of a condition for which treatment is

available. Failure to detect or rule out the presence of a disease or condition may result in poor quality of care and impact patient well being. Evidence in a recent meta-analysis found that the risk of underutilization was almost twice the levels of over utilization (44.8% risk of underutilization versus 20.6% risk of overutilization across all test types) (Zhi, 2013).

Table 1. Indicators of undertesting (Zhi, 2013)

Indicators	References
A particular disease, chronic or genetic condition is present and testing is indicated	Fergeson, 2009
A patient's health status has changed or sufficient time has elapsed in the progress of the disease	Were, 2011
A failure to test within a set time frame	Leaver, 2009
A particular chronic condition requires routine monitoring	Canas, 1999; Laxmisan, 2011
Prior test results suggest that additional testing should be performed	Mepham, 2009; Lee, 2011
A test is indicated based upon a specific national guidelines	Mepham, 2009

Bates, et al. defined redundant tests as those that "follow other tests of the same type, can be prospectively identified and have little chance of yielding clinically important information" (Bates, 1998b). Overtesting or redundant testing has been shown to occur for a number of reasons noted in Table 2. Overtesting is problematic for several reasons. First, overtesting is an indication of substandard patient care given the near term potential physical impact that testing has on the patient. Tests that are deemed to be unnecessary can create undue patient hardship resulting from test administration. Second, increased test utilization increases the risk of false-positive tests that may adversely impact patient well being. Third, increased false-positive results can also give rise to the "Ulysses syndrome" which is defined as the tendency towards complete and aggressive work-ups to identify the health status and treatment plan for a patient who does not have the disease. This results in unnecessary economic cost associated with both administering the test as well as future medical costs for unnecessary downstream treatment (Rang, 1972; Dorevitch, 1992). Physician ordering practices, including panel-

based ordering and defensive medicine (Mello, 2010) are primary drivers of inappropriate testing (Epstein, 1986; Williams, 1982; McGillvray, 1993; Bugter-Maessen, 1996; Griffith, 1997). When examining testing from a population-based perspective across all care settings, one source of overtesting may result from a lack of clinician awareness of prior test results performed by other clinicians for a patient. Without a mechanism for sharing prior test results, clinicians in this situation may repeat tests.

Table 2. Indicators of overtesting (Zhi, 2013)

Indicators	References
The patient does not meet demographic characteristics that are appropriate for administering the test	Poteat, 2000; Kerfoot, 2007
The patient lacks particular symptoms or indications that warrant a test	Mordasini, 2002; Affolter, 2003
Normal test results are not used to exclude diagnoses	Miyakis, 2006
Absence of previous abnormal values or worsening clinical indications	Eva, 2009
A test is repeated within a given time interval in which the test will fail to obtain new clinical evidence of value to the clinician	Bates, 2009; Huissoon, 2002; Kwok, 2005; Laxmisan, 2011
A test is repeated despite the fact that the results of the index test will never change	Riegert-Johnson, 2008
A test is a repeat of a previous positive test	Hanna, 2009
A test is used for the wrong purpose	Ozbek, 2004; Walters, 2004
A test results will not alter or impact patient care	Miyakis, 2006
A test fails to meet other evidence-based testing guidelines or standards defined by national policies or guidelines for appropriate care	Rehmani, 1999; Merlani, 2001

One broad objective of federal subsidies to promote investments in electronic health record technology is to promote improved information sharing by clinicians This is based upon the view that improved care coordination, including information sharing, leads to better health outcomes and lower healthcare costs. However, results remain mixed (Van Walraven, 2006; AMA, 2009; NQF, 2011). Effective care coordination remains problematic in most developed countries (Schoen, 2011). Since patients commonly receive care across multiple clinicians, often across multiple health settings or health systems with different EHRs, clinicians may lack access to a patient's prior test results and, subsequently, reorder tests that would not be necessary if the prior test results were accessible. Access to prior test results enabled through electronic sharing

of health information using a common EHR or through the exchange of prior test information between provider's separate EHR's using health information exchange should lower the incidence of inappropriate testing.

Studies on the incidence of redundant testing in children, as well as the potential impact of information sharing in reducing redundant testing in this pediatric population, are particularly sparse. Yet, evidence suggests that redundant testing patterns may vary substantially by age suggesting a need for further research (Van Walraven, 2003). Isolating the level of inappropriate or redundant testing that can be eliminated through better information sharing of patient test information, both within and among health systems that care for children, can improve care quality and lower cost.

BASIS FOR UNDERSTANDING

Repetition by clinicians of the same or similar tests with a given patient is common and varies by age (Bates, 1998; Van Walraven, 1998). However, not all repeat tests are necessary or appropriate for care (Zhi, 2013). Inappropriate testing includes both overtesting and undertesting (Zhi, 2013). Outcomes associated with overtesting include unnecessary physical and emotional hardship and economic cost that can justify efforts to eliminate unnecessary or potentially redundant tests (Rang, 1972; Dorevitch, 1992) .Limited evidence suggests that an electronic health record (EHR) may reduce redundant lab and radiology testing by making previous test results accessible to clinicians at the point of care (Bates, 1999). Results of research on the impact of EHR use on radiology and lab testing in pediatric populations is limited and inconclusive (Tuefel, 2010a).

The impact of the accessibility of prior test results on redundant test levels has been examined in individual health system settings. No studies were found linking accessibility of prior test results via an electronic health record with test redundancy in a

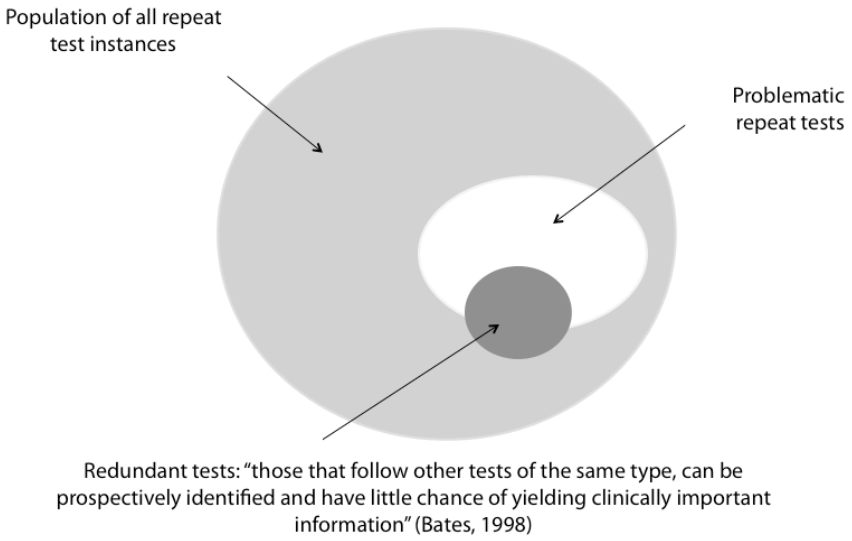
population-based study. It's generally accepted that children often receive care across multiple health systems. Each individual health system has an EHR that contains the results of lab and radiology tests ordered by clinicians within that single health system. Lab and radiology tests for the same patient may be in different EHRs if they are cared for in different health systems. Given this fact, lab and radiology test information is less likely to be available or accessible for the clinician at the point of care if the patient results are in more than one EHR within more than one organization As a result, it is anticipated that a higher level of redundant testing exists among children receiving care from more than one health system than for children who receive care from one organization due to a lack of physician access to a patient's prior test results.

MEASUREMENT CONSTRUCTS

To provide a basis for understanding and to characterize this theory, several measurement constructs were defined. A "**test instance"** was the unit of measure defined as any medical test performed by a clinician in a home care, primary care, outpatient, emergency room, inpatient, nursing home or other public health setting to provide information on a patients health status for screening, diagnosis, treatment or monitoring purposes. A "**repeat test instance"** was defined as a second lab or radiology test that follows a preceding instance of the same test (index test) for the same patient during the study period. This required an exact match of the index test and repeat test CPT (Current Procedure Terminology) code. This approach precludes the matching of tests based upon the presence of test result information that may be available through related but different tests or through test panels. A **"health system"** was defined as a single network of clinics, hospitals, specialty programs and long-term care facilities under a common ownership structure designed to deliver health care. An important characteristic of single health systems in this study population is the presence

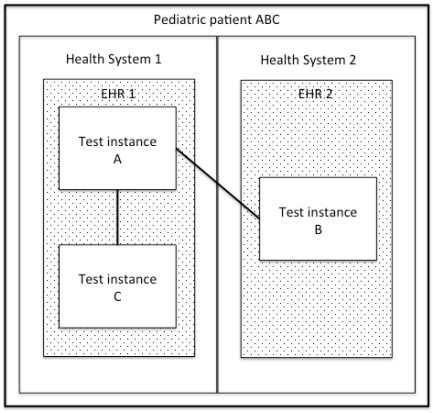
of a distinct "**electronic health record system**" in each health system containing all information regarding patient care delivered within that health system (MDH, 2013ab). **"Accessible prior test results"** were deemed accessible to the clinician if the patient received all care within a single health system. **"Facility type"** characterizes the location where the index or repeat test instance was placed, including inpatient, outpatient, primary care or other facility type. **A "redundant test"** is defined based upon Bates criteria as "tests that follow other tests of the same type, can be prospectively identified and have little chance of yielding clinically important information" (Bates, 1998). Identification of a redundant test typically requires that one has complete patient information, including the actual test values of index and repeat tests to correctly classify a test as redundant. In population-based studies in the United States, test information is captured decentrally within an individual health system often making collection of test results impractical. A **"problematic repeat test"** was defined for purposes of these studies and included any repeat tests with one or more characteristics that suggest a higher level of test redundancy. Figure 1 clarifies the distinction between the different classifications of repeat tests with problematic repeat tests a subset of repeat tests. Useful criteria for problematic repeat tests is then designed using available population data to capture a significant majority of actual redundant tests within the population.

Figure 1. Classifying repeat tests



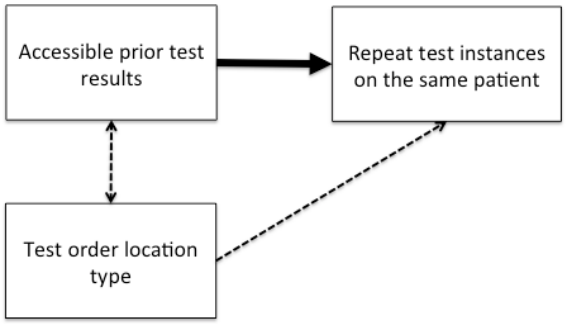
Using these terms, a simple model was developed to provide context for further study as noted in Figure 2. The model depicts patient ABC, a pediatric patient, receiving care from two distinct health systems, health system 1 and health system 2. Each health system has a distinct electronic health record system (EHR 1 and EHR 2) that captures patient test information on patient encounters that occur within that health system. In the model, patient ABC has three distinct test instances A, B and C. Test instances A and C were performed within the same health system with test information for both tests captured in a single electronic health record system (EHR 1). Test instances A and B were performed at separate health systems with data for each instance captured separately by the health system clinician that ordered the test performed.

Figure 2. Contextual model for a pediatric patient receiving care from more than one health system



Examining Figure 2, three things are anticipated. First, test instance B is more likely to be a repeat test instance of the same test than test instance C. Second, the incidence of repeat test instances will be higher in patient ABC than in a second patient who receives all patient care within a single health system with a single electronic health record system. Third, among the same facility types, the likelihood that test instance B is a repeat test instance of the same test relative to test instance C remains significant. The working theory is that a portion of repeat test instances result from a lack of clinician access to prior clinical information observable within an EHR and that clinicians with access to prior clinical information through an EHR will order fewer repeat tests than clinicians who do not have access to prior clinical information. For testing purposes, this general association can be characterized as noted in the visualization in Figure 3.

Figure 3. Model of the association between the accessibility of prior test results available through an electronic health record system and the incidence of repeat test instances



In conducting this evaluation, results described above may be observed but an association will by unclear without examining in more detail specific circumstances. This may result from the presence of other potential risk factors that affect the ability to detect the impact of available prior clinical information on repeat test instances. These may include patient characteristics; test characteristics; disease characteristics; patient health care utilization characteristics; health system characteristics and electronic health record characteristics associated with both access to prior clinical results and the likelihood of repeat test instances (Van Walraven, 2003; Zhi, 2013).

Multivariate logistic regression provides a reasonable basis for modeling this association, including adjusting for other known risk factors that may be associated with care. The two primary equations of multivariate logistic regression include the following:

(Equation 1)

$$\pi(X) = exp(\beta_0+\beta_1X_1+\beta_2X_2+ \ldots +\beta_pX_p)/$$

$$(1 + (exp(\beta_0+\beta_1X_1+\beta_2X_2+ \ldots +\beta_pX_p))$$

which gives us the probabilities of outcome events given the covariate values X_1, X_2, $X_3 \ldots X_p$. Transforming the dichotomous outcome using the logit transformation gives us a standard multivariate linear regression model as follows:

(Equation 2)

$$logit(\pi(X)) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_p X_p$$

The outcome of the multivariate logistic regression model is the logit(π(X)) – a binary outcome variable (0/1) that allows us to compare the odds that a particular test instance is a repeat test instance based upon whether or not the patient received care within a single health system with a single EHR or across multiple health systems with results captured across multiple EHRs.

To examine the effect of a common health system and EHR on the incidence of repeat test instances by patient, an alternate regression modeling approach is required given the presence of a count variable identifying the number of repeat test instances by patient. For these purposes, the use of a negative binomial regression is appropriate. A negative binomial distribution is a discrete probability distribution of the number of successes in a series of trials before a non-random number of failures occurs. Negative binomial regression is useful when dealing with over-dispersed discrete data and provides a more accurate estimator than simple Poisson regression in most cases (Du, 2012).

STUDY HYPOTHESIS

The underlying hypothesis for these population-based studies is that a portion of repeat test instances within a pediatric population result from a lack of clinician access to prior test results observable within an electronic health record. Clinicians with access to

prior test results observable through an electronic health record will order fewer repeat tests than clinicians who do not have access to prior test results.

SPECIFIC AIMS

The aims of this research include the following:

1. Aggregate all pediatric claims data for the defined study population for analysis and characterize the repeat test instances within the pediatric population, including the effect of multiple health system use by patient on the odds of repeat test instances generally;
2. Measure the effect of facility type (i.e., hospital, outpatient primary care) as a risk factor on the effect of multiple health system use by patient on the odds of repeat test instances within the pediaric population;
3. Define a reasonable criteria for problematic repeat tests for lead testing in children.
4. Measure the effect of health system use on the incidence of problematic repeat lead testing to determine the impact that assumed access to a common health record may have on problematic test levels.

The first paper "Characteristics of Repeat Test Instances in a Pediatric Population" characterizes the nature of test repetition within a pediatric population in an effort to better understand the nature of repeat test instances and risk factors associated with repeat test instances, including the presence of an accessible electronic health record. The study results identify important risk factors associated with repeat test instances in children and demonstrate that patients receiving care in one health system with an accessible electronic health record is associated with a significantly lower

incidence of repeat test instances than patients who receive care from multiple health systems with multiple electronic record systems.

The second paper, “Effect of Facility Type on the Risk of Repeat Test Instances in a Pediatric Population” examines the effect that facility type has on the association between patient use of multiple health systems and the level of repeat test instances. The study results demonstrate that facility type has a significant effect on the relationship between the presence of an accessible electronic health record and repeat test instances.

The third paper, “Effect of an Accessible Electronic Health Record on the Incidence of Problematic Repeat Lead Testing in a Pediatric Accountable Care Population” examines the impact that the accessibility of prior test results has on problematic repeat lead testing in a pediatric population. The study defines a reasonable criteria for the detection of problematic repeat lead tests and characterizes the nature and level of problematic repeat lead tests within a pediatric population. The study results demonstrate that use of a single health system with prior lead test results accessible through a common electronic health record is associated with significantly lower odds of problematic repeat lead testing.

ARTICLE #1: CHARACTERISTICS OF REPEAT TEST INSTANCES IN A PEDIATRIC POPULATION

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Running head: electronic health record and repeat test instances

Key words: electronic health record, population health management, children's hospitals, test repetition

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SUMMARY

Background

Repetition by clinicians of the same or similar tests with a given patient is common. However, not all repeat tests are necessary or appropriate for optimal care. Overtesting can result in unnecessary emotional hardship and economic cost. Limited evidence suggests that an electronic health record (EHR) may reduce redundant lab and radiology testing by making previous test results accessible to physicians, though research on the potential effect in pediatric populations is sparse. The purpose of this study is to characterize the nature and scope of repeat testing within a pediatric population and to identify significant risk factors associated with repeat test instances.

Methods

A retrospective cross-sectional design was used to measure initial and repeat test instances. The study population consisted of a continuing Medicaid population cohort of 12436 children (n=9153 patients with at least one test (68856 tests)) defined under a three-year demonstration project agreement between Children's Hospitals and Clinics of Minnesota (CHC-MN) and the Minnesota Department of Human Services (DHS) from 2012 to 2014. The study setting included all healthcare service organizations in the state of Minnesota that delivered health services to the defined study population and were reimbursed for services by the DHS under Medicaid. The study period was a one-year time frame ending September 30, 2013. Regression methods were used to test for significant associations between the outcome variable, repeat test instance and the primary explanatory variable health system use.

Results

The overall test repetition risk during the study period was 26.24% (n=68856 total radiology and lab tests). Pediatric patient characteristics significantly associated with a repeat test instance of the same test included age, residence, insurance plan type, test order location type, patient health status, patient test volume and availability of prior test results. The odds that a test was a repeat test instance were significantly higher when patients received care from multiple health systems and patient care information was captured on multiple different electronic health record (EHR) systems [adjusted OR 1.30 (95%CI: 1.25-1.35)]. Among patients with 25 or fewer test instances, the adjusted OR was 1.09 [95%CI: 1.02-1.15]. Similarly, the incidence of repeat test instances per patient was significantly higher when prior test results were not accessible [adjusted incidence rate ratio (IRR) 1.78 (95% CI: 1.66-1.91)]. Among patients with 25 or fewer test instances (n=8760 patients), the association between health system use and incidence of repeat test instances per patient during the study period remained statistically significant [adjusted IRR 1.40 (95% CI: 1.31-1.50)].

Conclusions

Pediatric patients who use more than one health system with patient information captured on more than one EHR have a higher level of repeat test instances of the same test than patients who receive all care within one health system using a single EHR. This may be due in part to a lack of clinician access to prior test results and is potentially redundant. Both a common electronic health record and health information exchange are potentially useful tools in reducing the incidence of repeat test instances in populations that receive care from multiple health systems.

BACKGROUND

Repetition by clinicians of the same or similar tests with a given patient is common (Bates, 1998b; Van Walraven, 1998). Repeat testing occurs for a number of reasons. A particular test may require multiple instances to obtain useful information. A particular disease or treatment may require multiple results to obtain a clear understanding of disease progression or the impact of a health intervention over time. An initial test result is unclear or inconclusive requiring a repeat test. Risk factors that influence the level of repetitive testing include patient demographic factors (including age, sex, race); test-related factors (including the purpose of the test, the test type and test accuracy); the nature of the condition being studied (including disease type, disease severity, presence of comorbidities particularly chronic conditions); and other factors including the location of care and the passage of time (Van Walraven, 2003; Zhi, 2013). Studies on the incidence of repetitive testing in children are sparse. Yet, evidence suggests that repetitive testing patterns may vary substantially by age (Van Walraven, 2003).

Not all repeat tests are necessary or appropriate for care resulting in meaningful levels of both overtesting and undertesting. Inappropriate testing may result from failing to administer either index or repetitive tests when such tests are warranted, for screening, diagnosis or treatment purposes (cited as undertesting or missing tests). Inappropriate testing may also result from administering index or repeat tests that are not required for necessary or appropriate care (often noted as redundant or excess testing) (Zhi, 2013).

Overtesting is problematic for several reasons. First, overtesting is an indication of substandard patient care given the near term potential physical impact that testing has on the patient. Tests that are deemed to be unnecessary can create undue patient

hardship resulting from test administration, particularly among children. Second, increased test utilization increases the risk of false-positive tests that may impact patient well-being. Third, increased false-positive results can also give rise to the "Ulysses syndrome" which is defined as the tendency towards complete and aggressive work-ups to identify the health status and treatment plan for a patient who does not in fact have the disease. This results in unnecessary economic cost associated with both administering the test as well as future medical costs for unnecessary downstream treatment (Rang, 1972; Dorevitch, 1992). Physician ordering practices, including panel-based ordering and defensive medicine (Mello, 2010) are primary drivers of overtesting (Epstein, 1986; Williams, 1982; McGillvray, 1993; Bugter-Maessen, 1996; Griffith, 1997).

Examining patient testing from a population-based perspective across all care settings, one source of overtesting may result from a lack of clinician awareness of prior test results performed at other health care locations or by other clinicians. Because patients commonly receive care across multiple health settings or health systems with different EHRs, providers often lack access to a patient's prior test results and reorder tests that would not be necessary if the prior test results were accessible. Without a mechanism for sharing prior test results, clinicians in this situation may repeat tests.

Limited evidence suggests that an electronic health record (EHR) may reduce redundant testing by clinicians, including lab and radiology tests, by making previous test results accessible (Bates, 1999). One broad objective of federal subsidies to promote investments in electronic health record technology, including Stage 3 meaningful use objectives, is to promote improved sharing of patient information, including test results, across health systems (HHS-ONCHIT, 2014). This is based upon the view that improved care coordination including information sharing leads to better health

outcomes and lower healthcare costs, though results of such efforts remain mixed (Van Walraven, 2006; AMA, 2009; NQF, 2011).

The purpose of this study is to characterize the scope and nature of repeat testing within a pediatric population and to identify significant risk factors associated with repeat test instances in children, including measuring the impact of accessibility of prior test results available through an accessible medical record on repeat test instances.. The underlying hypothesis is that a portion of repeat test instances result from a lack of physician access to prior clinical information observable within a patient electronic health record (EHR) and may be redundant. As a result, patients receiving care across multiple health systems, each with a separate electronic health record system, will have a higher incidence of repeat test instances. Reducing rates of potentially excess testing by improved sharing of patient information can lower the burden on children, including the physical and mental impact of testing; improve patient care; and potentially lower the cost of care. IRB approval for this study was obtained from the Minnesota Department of Human Services (IRB# 280), Children's Hospitals and Clinics of Minnesota (IRB# 1402-022) and the University of Minnesota (IRB# 1403E49003).

METHODS

The study objectives were to measure the prevalence of multiple lab and radiology test instances in a pediatric population and then to characterize significant patient, physician and test factors that may impact repeat test instances. Differences in the level of repeat test instances were then tested between patients that have all tests performed within a single health system on a single electronic health record versus patients that have tests performed across multiple health systems each with a distinct electronic health record system.

Several constructs were used for purposes of the study. A "**test instance"** was the unit of measure for this study and was defined as any medical test performed by a clinician in a home care, primary care, outpatient, emergency room, inpatient, nursing home or other public health setting, to provide information on a patients health status for screening, diagnosis, treatment or monitoring purposes. A "**repeat test instance"** was defined as a second lab or radiology test that follows a preceding instance of the same test (index test) for the same patient during the study period. This required an exact match of the index test and repeat test CPT code. This approach precludes the matching of tests based upon the presence of test result information that may be available through related but different tests or through test panels. "**Probability of repeat test instances"** was defined as the probability that multiple instances of the same test are performed on the patient during the study period defined and was calculated by dividing the count of repeat test instances by the total test count. Repeat test instances were analyzed by test instance and by patient. **"Days-to-next test instance"** was defined as the number of days between the index test and the next test instance (next test instance date – index test date). A **"health system"** was defined as a single network of clinics, hospitals, specialty programs and long-term care facilities under a common ownership structure designed to deliver health care. An important characteristic of single health systems in this study population is the presence of a distinct electronic health record system in each health system containing all information regarding patient care delivered within that health system (MDH, 2013 a,b). Given this, for purposes of this study, **"accessible prior test results"** were deemed accessible to the clinician via a common electronic health record if the patient received care from a single health system. A **"redundant test"** is defined based upon Bates criteria as "tests that follow other tests of the same type, can be prospectively identified and have little chance of yielding clinically important information" (Bates, 1998b). Identification of a

redundant test typically requires that one have complete patient information, including the actual test values of index and repeat tests to correctly classify a test as redundant. In population-based studies in the United States, test information is captured decentrally within individual health system making collection of test results impractical. A **"problematic repeat test"** was defined for purposes of these studies using available information and included any repeat tests with one or more characteristics that suggest a higher level of test redundancy. Figure 1 clarifies the distinction between the different classification of repeat tests.

A retrospective cross-sectional design was used to conduct the analysis. The study population consisted of a Medicaid total population cohort of 15886 children defined under a three-year demonstration project agreement between Children's Hospitals and Clinics of Minnesota (CHC-MN) and the Minnesota Department of Human Services (DHS) from 2012 to 2014. CHC-MN is part of a distinct class of hospitals known as children's hospitals that exist to exclusively serve the needs of children and adolescents. Children's hospitals are characterized by expertise in treating children, including children with rare diseases, and in providing greater attention to psychosocial support for children and families.

Patient attribution to the Medicaid patient cohort was based upon (a) Medicaid enrollment status and (b) whether the patient received a plurality of their care through CHC-MN primary care clinics. Patient attribution for purposes of this study was measured as of December 31, 2013. All test instance activity for this cohort represented by claims for laboratory services for the previous 12 months ending September 30, 2013 was examined. For purposes of this study, all patients that did not remain on Medicaid for the complete period of the study were excluded. The final study population cohort consisted of 12436 patients with 9153 patients having at least one laboratory test claim (n=68856 total tests).

The study setting includes all healthcare service organizations in the State of Minnesota that delivered health services to the defined study population and were reimbursed for services by the Minnesota Department of Human Services under the Medicaid program. Care settings included hospitals, emergency rooms, medical centers, outpatient and primary clinics, home care, nursing homes and other long term care facilities, transportation assistance, public health agencies and other non-profit organizations. CHC-MN and its primary and specialty care network affiliates included in the demonstration project accounted for approximately 30% of the total health service charges attributed to the study population. CHC-MN and its network affiliates accounted for approximately 70% of test order volume in the population. EHR adoption is high within the provider population serving study patients. The 2013 e-Health Survey conducted by the Minnesota Department of Health notes that 87% of clinics and 96% of hospitals, labs and local health departments have adopted electronic health record technology or equivalent health information technology (HIT) (MDH, 2013 a,b). The Department of Human Services provided patient and submitted claims data for all covered care paid by Medicaid provided to the patient cohort, including claims submitted by healthcare organizations or radiology and lab services for testing purposes. EHR utilization data was provided by the Minnesota Department of Health (MDH, 2013 a,b).

Descriptive statistical methods were used to characterize the population and identify potential risk factors for repeat test instances in children. The unit of analysis was either a test instance or a patient. The outcome variable was defined two ways for test purposes: as a binary variable identifying the instance as a repeat test instance (0/1) and as an integer count of the total test repeats by patient. Potential explanatory variables were identified for testing based upon known and potential patient, physician and test factors that may impact repeat test instances in adult populations including patient demographics (age, gender and residence); patient health status (number of

chronic conditions, general health status, number of health systems used and total patient test volume); and approach to care (care location, test type) (Van Walraven, 2003; Zhi, 2013). Patient general health status was measured by the resource utilization band classification system devised using the Johns Hopkins ACG system (Johns Hopkins, 2009). The ACG system was designed to measure multi-morbidities and has been shown to have a strong correlation with overall patient health (Starfield, 2011).

The primary explanatory variable, health system use, was defined two ways for purposes of testing: as a binary variable (one health system/more than one health system) and as discrete integer variable based upon the number of health systems that performed tests for the patient. An important characteristic of a single health system is the presence of a single electronic health record that contains all patient data. Services by clinicians were based upon the national physician identifier (NPI) code for the provider receiving payment for services (n=447). Instances were then individually reviewed and grouped by health system (n=292 health systems), each with a unique electronic health record instance. Univariate and multivariate logistic regression were deployed to test for significant associations between explanatory variables and the outcome variable. Negative binomial univariate and multivariate regression were used in analyzing patient-level counts of test instances. Results by test instance and by patient were reported separately.

RESULTS

Of patients that received at least one test, the patient population ranged from premature birth to 21 years with the majority of patients between 1-9 years of age (mean age 7.17 years (median 6.19)). Fifty-one percent (51.94%) of patients were male with 74.05% of the patient population living within the two-county metropolitan area including the urban centers of Minneapolis and St. Paul. Over three-fourths of patients were part

of a Medicaid managed care plan (76.64%) versus Medicaid fee for service. Patients with at least one test performed had an observed higher incidence of chronic conditions and poorer health status than patients with no tests performed. Patients had tests ordered from an average of between 1 and 2 health systems with 32.84% of patients using more than one health system. A complete description of the study population is noted in Table 3.

Table 3. Study population characteristics

Characteristic	Categories	All patients	% Total	Patients >0 tests	% Total	Sig	95% confidence interval for risk of repeat test instance
Count	Total	12436		9153	100.00%		
Sex	Male	6503	52.29%	4754	51.94%		1.03 (95%CI: 0.99-1.06)
Age (at start of study)	Mean (median)	7.09 (6.22)		7.17 (6.19)		*	1.02 (95%CI: 1.01-1.02)
	Interquartile range	2.89 - 10.79		2.58-11.10			
	<1	1340	10.78%	960	10.49%	Ref	-
	1-4	3772	30.33%	2877	31.43%	*	1.45 (95%CI: 1.35 - 1.56)
	5-9	3726	29.96%	2574	28.12%	*	1.55 (95%CI: 1.44 - 1.67)
	10-14	2550	20.50%	1825	19.94%	*	1.35 (95%CI: 1.27 - 1.45)
	15-17	605	4.86%	505	5.52%	*	1.54 (95%CI: 1.41 - 1.69)
	17-20	442	3.55%	412	4.50%	*	2.13(95%CI: 1.96 - 2.32)
Residence by type	Urban	9278	74.61%	6778	74.05%	*	1.05 (95%CI: 1.01 - 1.09)
	Suburban/Rural	3158	25.39%	2375	25.95%		
Chronic condition count	0	7112	57.19%	4869	53.20%	Ref	-
	1	2833	22.78%	2150	23.49%	*	1.36 (95%CI: 1.29 - 1.44)
	2	1124	9.04%	910	9.94%	*	1.56 (95%CI: 1.48 - 1.67)
	3	517	4.16%	428	4.68%	*	1.85 (95%CI: 1.71 - 1.99)
	4	316	2.54%	277	3.03%	*	2.20 (95%CI: 2.03 - 2.38)
	5+	534	4.29%	519	5.67%	*	5.10 (95%CI: 4.85 - 5.36)
Patient health status	1	1535	12.34%	622	6.80%	Ref	-
	2	3987	32.06%	2497	27.28%	*	1.99 (95%CI: 1.65 - 2.41)
	3	5273	42.40%	4481	48.96%	*	2.85 (95%CI: 2.38 - 3.42)
	4	1187	9.54%	1103	12.05%	*	4.44 (95%CI: 3.69 - 5.33)
	5	454	3.65%	450	4.92%	*	10.90 (95%CI: 9.08 - 13.08)
Plan type	Managed care	9629	77.43%	7015	76.64%	*	0.51 (95%CI: 0.49-0.52)
	FFS	2807	22.57%	2138	23.36%		
Health system use	One system			6147	67.16%		
	Multiple systems			3006	32.84%	*	1.81 (95% CI: 1.74-1.87)

*Significant (p<.05)
Ref = reference category

Total test instances were 68856 that included 57997 lab instances (84.23%) and 12869 radiology instances (15.77%), or an average of 6.34 lab instances and 1.19 radiology instances per patient with at least one test. Test instance volume range per person during the study period was considerable (lab instances: 0 – 419 & radiology instances: 0 – 79). Repeat test instances accounted for 26.24% of the total test

population. Population characteristics significantly associated with risk of repeat test instances as noted in Table 1 included both mean age at visit (in years) and by age group, urban residence, use of a managed care Medicaid plan. Looking at the impact of patient heath status, each one-unit increase in the number of chronic condition counts (reference count = 0) was associated with a significant increase in the risk of a repeat test instance. Similarly, patients with a higher estimated resource utilization band as measured by the modified ACG score referenced earlier were at increasingly greater risk of repeat test instances with each one unit increase in the band category (reference band = 1).

As anticipated, the probability of repeat test instances increased as the days to next-test-instance increased. As noted in Table 2, nine percent (9%) of repeat test instances occurred within 1 day - 22% of multiple instances occurred within 7 days of the first test instance and 44% occurred within 30 days. Mean days to next test instance was 67.73d. Average days to next test instance varied significantly between lab and radiology tests with mean days to next test instance for lab tests 1.31 times longer (95%CI: 1.255 – 1.386) than for radiology tests with the majority of the difference coming within the first seven days of the index test as noted in Table 4.

Table 4. Repeat test instances by lab and radiology by days to next test instance

				Probability of Repeat Test Instances		
Attribute	Days to next test instance	N	Cum %	Overall	Lab Only	Radiology Only
Probability of multiple test instances	365	18071	100%	26.24%	26.38%	25.51%
	180	16287	90%	23.65%	23.72%	23.33%
	90	12759	71%	18.53%	18.33%	19.59%
	60	10745	59%	15.61%	15.19%	17.82%
	30	7979	44%	11.59%	11.00%	14.74%
	15	5745	32%	8.34%	7.66%	11.98%
	7	3964	22%	5.76%	4.97%	9.94%
	6	2860	16%	4.15%	3.18%	9.37%
	5	2695	15%	3.91%	2.94%	9.11%
	4	2490	14%	3.62%	2.67%	8.68%
	3	2295	13%	3.33%	2.40%	8.33%
	2	2046	11%	2.97%	2.12%	7.53%
	1	1624	9%	2.36%	1.58%	6.49%

Observed probability of repeat test instances was also found to vary considerably with the observed odds of a repeat test instance occurring in a hospital setting (53.40%), more than double the observed probabilities of outpatient, primary care and other test instance location types as noted in Table 5.

Table 5. Repeat test instances by facility type – overall and by laboratory and radiology testing

			Probability of Repeat Test Instances		
Test order location type	**N**	**% Total**	**Overall**	**Lab Only**	**Radiology Only**
Inpatient	1883	2.73%	53.40%	36.14%	56.45%
Outpatient	50359	73.14%	25.80%	26.70%	19.81%
Primary care	13751	19.97%	25.30%	26.17%	21.04%
Other	2863	4.16%	21.30%	21.20%	22.63%

Observed variation by test type was meaningful with therapeutic drug assays, tissue typing and drug testing having the highest probability of repeat test instances. Among the top five most common test groups (microbiology, chemistry, hematology, organ or disease-oriented panels and urinalysis), observed probability of repeat test instances ranged from 25-30% over the study period as noted in Table 6.

Table 6. Repeat test instances by CPT lab group classification

	Study period				
CPT Lab Group Classification	Total	% total	Repeat tx	% total	Repeat risk
Microbiology	20,153	34.75%	5,141	33.60%	25.51%
Chemistry	16,882	29.11%	4,912	32.10%	29.10%
Hematology and coagulation	8,681	14.97%	2,146	14.03%	24.72%
Organ or disease-oriented panels	4,009	6.91%	1,130	7.39%	28.19%
Urinalysis	3,568	6.15%	988	6.46%	27.69%
Immunology	2,883	4.97%	475	3.10%	16.48%
Surgical pathology	638	1.10%	64	0.42%	10.03%
Therapeutic drug assays	509	0.88%	317	2.07%	62.28%
Transfusion medicine	213	0.37%	47	0.31%	22.07%
Cytogenetic studies	121	0.21%	2	0.01%	1.65%
Cytopathology	104	0.18%	27	0.18%	25.96%
Other procedures	71	0.12%	21	0.14%	29.58%
Drug testing	53	0.09%	18	0.12%	33.96%
Molecular pathology Tier 1	47	0.08%	-	0.00%	0.00%
Tissue typing	32	0.06%	11	0.07%	34.38%
Molecular pathology Tier 2	21	0.04%	-	0.00%	0.00%
In vivo lab procedures	10	0.02%	2	0.01%	20.00%
Consultations	1	0.00%	-	0.00%	0.00%
Reproductive medicine procedures	1	0.00%	-	0.00%	0.00%

Looking at specific labs tests by Current Procedural Terminology (CPT) code 2012 edition, the most common lab tests performed were strep, culture screens (related to strep testing), blood count (both hemoglobin only and complete) and lead testing as noted in Table 7.

Table 7. Multiple lab test instances by most common CPT code

		Study period				
Individual CPT Test	CPT code	Total	% total	Repeat tx	% total	Repeat risk
RAPID STREP	87880	6,196	10.68%	2203	14.40%	35.56%
STREP CULTURE	87081	3,203	5.52%	882	5.76%	27.54%
COMPLETE BLOOD COUNT WITH DIFFERENTIAL	85025	3,046	5.25%	1044	6.82%	34.27%
BLOOD COUNT; HEMOGLOBIN ONLY	85018	2,654	4.58%	379	2.48%	14.28%
LEAD	83655	2,073	3.57%	217	1.42%	10.47%
URINE CULTURE	87086	1,785	3.08%	450	2.94%	25.21%
BASIC METABOLIC PANEL	80048	1,510	2.60%	495	3.24%	32.78%
URINALYSIS,BY DIPSTICK, AUTOMATED WITH MICROSCOPY	81001	1,398	2.41%	430	2.81%	30.76%
VITAMIN D 25 HYDROXY	82306	1,345	2.32%	270	1.76%	20.07%
URINALYSIS,BY DIPSTICK, AUTOMATED WITHOUT MICROSCOPY	81003	1,306	2.25%	277	1.81%	21.21%

Meaningful differences in the observed probability of repeat test instances by imaging platform and individual test were apparent as well. The majority of radiology tests performed were radiography tests (77.10% of all tests) with a probability of repeat test instances of 28.78%. The next most common tests were ultrasound and computerized tomography (CT) as noted in Table 8.

Table 8. Repeat test instances by CPT radiologic code sub-category

	Study period				
CPT Radiologic Subcategory	Total	% total	Repeat tx	% total	Repeat risk
Diagnostic imaging:					
Imaging/radiology (radiography)	8,354	77.10%	2404	86.91%	28.78%
Computed tomography (CT)	617	5.69%	82	2.96%	13.29%
Magnetic resonance imaging (MRI)	440	4.06%	44	1.59%	10.00%
Fluoroscopy	97	0.90%	20	0.72%	20.62%
Other	114	1.05%	12	0.43%	10.53%
Diagnostic Ultrasound	887	8.19%	168	6.07%	18.94%
Bone/joint studies	278	2.57%	23	0.83%	8.27%
Nuclear medicine	48	0.44%	13	0.47%	27.08%
Other	24	0.22%	4	0.14%	16.67%

The most common tests included the both the single and two-view chest x-ray, x-ray of the abdomen, computerized tomography (CT) of the head/brain and x-ray of the foot. These same tests had the highest repeat test instances as well as noted in Table 9.

Table 9. Multiple radiology test instances by most common CPT code

		Study period				
Individual CPT Test	CPT Code	Total	% total	Repeat tx	% total	Repeat risk
RADEX CH 2 VIEWS - FRONT/LAT	71020	2700	24.86%	861	31.08%	31.89%
X-RAY EXAM OF ABDOMEN	74020	710	6.54%	138	4.98%	19.44%
X-RAY EXAM OF ABDOMEN	74000	493	4.54%	167	6.03%	33.87%
CMPT TOMOGRPH HEAD/BRAIN	70450	289	2.66%	57	2.06%	19.72%
X-RAY EXAM, CHEST, SINGLE FRONTAL	71010	891	8.21%	653	23.57%	73.29%
RADEX FOOT COMPLETE- 3+ VIEWS	73630	258	2.38%	40	1.44%	15.50%
US RETROPERITONEAL	76770	253	2.33%	41	1.48%	16.21%
RADEX ANKLE COMPLETE - 3+ VIEWS	73610	205	1.89%	30	1.08%	14.63%
RADEX PELVIS 1|2 VIEWS	72170	223	2.05%	44	1.59%	19.73%
BONE AGE STUDIES	77072	183	1.69%	12	0.43%	6.56%

Patients had tests ordered from between 1 and 11 unique health systems. Observed probability of repeat test instances involving patients using one system was 20.0% versus 31.1% for instances involving patients having test claims filed from more than one health system [OR 1.81 (95% CI: 1.74-1.87)]. Adjusting for confounding factors noted earlier, including total patient test instance volume, the difference remained significant [OR 1.30 (95% CI: 1.25-1.35)] as noted in Table 10.

Repeat test instance patterns reveal at least two underlying health care processes. Focusing on patients with 25 or fewer instances (n=8760) improves the ability to detect the probability that repeat test instances were due to patient use of multiple health systems rather than from scheduled test instances associated with children who have severe comorbidities. The odds of repeat test instances remained marginally significant for patients with 25 or fewer test instances as well at 1.09 [95% CI: 1.02-1.15].

Table 10. Unadjusted and adjusted odds ratio of a repeat test instance given patient used more than one health system

	Odds of repeat test instances (1)	
	All test instances (n=68856)	Test instances for patients with 25 or fewer test instances (n=48485)
Unadjusted	1.81	1.65
95% Confidence Interval	1.74-1.87	1.57-1.79
Adjusted (2)	1.30	1.09
95% Confidence Interval	1.25-1.35	1.02-1.15

Legend
(1) Results based upon logistic regression. Outcome variable equal to a multiple instance of the same test.
(2) Significant risk factors include sex, age, residence, chronic conditions, resource use, payer, total patient transaction count

Using negative binomial regression to measure the estimated incidence rate ratio of repeat test instances per patient, comparing patient using multiple health systems versus one health system, holding other variables constant, patients using multiple health systems had an incidence rate of repeat test instances that was 4.10 (95% CI 3.73-4.50) greater than for patients using a single health system. The significant positive association remained after adjusting for covariates [1.79 (95% CI: 1.66-1.91)] as noted in Table 11. On an adjusted basis, the association between health system use and incidence of repeat test instances during the study period remained significant at 1.40 [95% CI: 1.31-1.50] as noted in Table 11.

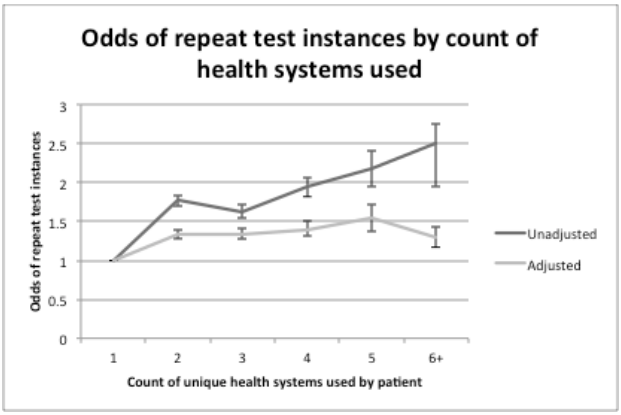
Table 11. Incidence rate ratio of repeat test instances per patient between patients using multiple health systems and patients using a single health system

	Incidence rate ratio of repeat test instances per patient (1)	
	All patients with at least one test instance (n=9153)	All patients with 25 or fewer test instances (n=8760)
Unadjusted	4.1	3.1
95% Confidence Interval	3.73-4.50	2.86-3.38
Adjusted (2)	1.79	1.40
95% Confidence Interval	1.66-1.91	1.31-1.50

Legend
(1) Results based upon negative binomial regression. Outcome variable equal to total multiple instances by patient.
(2) Significant risk factors include sex, age, residence, chronic conditions, resource use, payer, total patient transaction count

Stratifying the multiple test incidence rate ratio by the number of health systems seen by patient, a significant positive association was observed between the number of systems used by each patient and repeat test instance levels. The association remained after adjusting for identified risk factors as noted in Figure 4.

Figure 4. Odds of repeat test instances by patient by count of health systems used



DISCUSSION

Repeat test instances are often essential to quality care for screening, diagnosis and monitoring (Van Walraven, 1998; Bates, 1998; Zhi, 2013). The population-based results indicate that pediatric patients that receive care across multiple health systems supported by separate electronic health record instances have higher levels of repeat test instances after adjusting for identified risk factors.

Overall probability of repeat test instances was lower in the sample (26.24%) relative to studies of adult populations. Previous studies of population-based repeat test instances in adults in Canada measured the probability of repeat test instances at 56% for a set of 8 common tests (Van Walraven, 2003). A separate community-based study found a probability of repeat test instances of 38% over an eight-month period (Branger,

1995). Both these rates are higher than the levels identified in this study. Distinctions in adult versus children's health and health care may account for some of this variation. Pediatric care is focused on the growth and development of children thus impacting the nature and frequency of testing. Three of the top five most common lab tests found in the pediatric population are associated more commonly with childhood conditions (rapid strep, strep culture and lead testing) and were not included in a population-based study sample of common tests used to evaluate study repetition in adults (Van Walraven, 2003). More generally, evidence regarding differences in utilization patterns between adults and children are limited and the results are mixed. For example, evidence regarding differences in ICU utilization patterns in a hospital-based study between children and adults cite better mortality results for children but no significant differences in resource utilization patterns and overall treatment cost between the two groups (Seferian, 2001).

Consistent with studies in adults, certain factors were significantly associated with repeat test instances in children. Repeat test instances were associated with age, with patients greater than one-year old having significantly more repeat test instances than patients under the age of one. Repeat test instances were also associated with patient residence, with those in urban areas at slightly higher risk of repeat test instances. The health plan financing arrangement was also associated with increased risk of repeat test instances with Medicaid fee for service patients having a higher incidence of repeat test instances. Medicaid fee for service has been linked with increased utilization by physicians given the reimbursement structure in place that rewards utilization (Bindman, 1999; Gosden, 2000; Phillips, 2014).

Higher repetition levels for tests performed in a hospital were consistent with findings in larger adult populations (Valenstein, 1988; Bates, 1998a; Van Walraven, 2003). Higher levels of repeat test instances in hospital-based care may be, to some

degree, a function of the underlying conditions being treated and the underlying process of care. A short-term increase in repeat test instances is often associated with hospital-based care processes. The underlying care processes that drive short-term repetition in a hospital setting may differ substantially from factors that drive repeat test instances in other care settings. Hospital-based factors may include for example the presence of automated workflows or clinical pathways, including standard test order sets, that may institutionalize test repetition in inpatient care (Niazkhani, 2009; Maslove, 2011).

The population-based results support the underlying theory that a test for the same patient at a different health system on a different EHR is 1.3 times more likely to be a repeat test [adjusted OR 1.30 (95%CI:1.25-1.35)] than if the test were ordered by the same health system with accessible prior test results. Consistent with this, results also confirmed the hypothesis that the incidence of repeat test instances is higher [adjusted OR 1.79 (95%CI:1.66-1.91)] for patients having tests ordered from more than one health system where prior test results may not have been accessible. A high level of repeat test instances is associated with the care of children with multiple co-morbid conditions. Patients with more than 25 tests (n=393, 4.29% of population) during the study period were found to have more severe co-morbid conditions, often receiving home-based or nursing care. These children have significant prescribed test repetition associated with ongoing monitoring of health conditions. Removing this sub-group of patients from the general population, a better measure of the effect of an accessible health record on patients with mild to moderate chronic illness or more common childhood illnesses that may have regular yet unplanned and fragmented care across multiple health systems could be performed. The results suggest that when stratifying the population to remove patients with prescribed test repetition associated with multiple co-morbid conditions, the adjusted odds of repeat test instances for patients receiving care from more than one health system presumably without accessible test results

remains significant drops to 1.09 [95%CI: 1.02-1.15] . Similarly, the incidence rate ratio of patients with multiple tests results remains significant but also drops [1.40 (95%CI: 1.31 – 1.50)].

The fact that each health system has a separate electronic health record system makes it particularly difficult to separate the impact of accessible test results from an electronic health record from the effect of each health system's policies and practices on the incidence of repeat test instances. This gives rise to a possible alternative explanation for these results. Health information technology enables innovation but only to the extent that HIT availability aligns with the human decision-making needs of an organization. Evidence suggests that physicians will seek information only if it's deemed to be relevant to the decision at hand, reliable in terms of information quality and timely (Andrews, 2005; Coumou, 2006). Clinicians, for example, may have accessible test results from another health system but still elect to repeat tests as a matter of preference given concerns regarding the relevance and reliability of the test data or due to health system policy that encourages clinicians to repeat tests using only health system testing resources. The impact is that some portion of the incremental test repetition identified through this study may result from these mechanisms thus making it difficult to estimate the effective impact that making prior test results accessible through either a single electronic health record or through the health information exchange will have on the incidence of repeat test instances. Future study is required to separate the effect of health system policy from the impact of accessible prior test results on the level of repeat test instances.

LIMITATIONS

The cohort being studied is based upon an attribution formula that assigns patients to the ACO based upon (1) participation in a complex care coordination program

in place (selection of CHC-MN to receive care) and (2) plurality of care given at a children's hospital/clinic. Given that patients can elect where they receive a majority of their care, patients in effect self-select to the attributed population. This may impact the generalizability of external validity of the study results.

Children's hospitals have a set of potentially distinct patient and treatment characteristics from general hospital including the setting, patient demographics, the nature and severity of conditions treated and distinct protocols or pathways in place (Meurer, 1998; Merenstein, 2005). Care should be taken in applying these results across a general pediatric hospital population.

Limitations in the secondary use of Medicaid claims data for research are cited by some as problematic when it comes to claim accuracy and the lack of clinical specificity with regards to diagnoses and underlying test results (Hsia, 1988; Seiber, 2007; Chisholm, 2009; HHS-CMS, 2013). Standard audit processes for testing Medicaid claims error rates occur annually. The PERM (Payment Error Rate Measurement program) is sponsored by CMS and involves state evaluations on a rolling three-year test cycle. As of the 2010 test cycle (which includes Minnesota), the national error rate for payment was 1.89% +/- 0.62%. (range from 1-3%). State results range from 0.6 to 3.8%. Overall, Medicaid views these national results optimistically suggesting that no systemic problems exist in the results (Chisholm, 2009). Enrollment continuity, often cited as a problem in using Medicaid data, was addressed by limiting the population to those patients who were enrolled for at least 12 months (Crystal, 2007). Regarding the lack of complete information, such limitations are more a function of the nature of the study being conducted that uses the claims data than of the underlying limitations of the data itself (Dombkowski, 2012; Cooke, 2013). For purposes of this evaluation, the population-based approach to this study should limit the effect of limitations in the use of Medicaid claims data on the results of the study.

Information risk is also present based upon the use of test panels for administering testing services. It is possible that actual repeat test instances of useful comparable individual test measurements are higher than the results. In a separate analysis, repeat test instance levels were 54% higher when matching a simple index hemoglobin blood test (CPT: 85018) against any repeat test instance that includes an individual hemoglobin test measurement, including test panel results. The effect of this limitation would be to underestimate the prevalence of repeat test information in this study. This could impact the findings of this analysis if panel use varied significantly between index and repeat pairings within the same health system from pairings between two different health systems. If certain locations are more likely to use panels and these locations were more likely to be paired as either same or different, then there would be an effect. Further research is needed to define a meaningful approach to incorporating panel results in the study of test repetition and redundancy.

The statistical methods used for this study do not fully address the impact of correlated data on study results. Naturally occurring groups such as patients and health systems may have more similar observations than different groups. The lack of independence between individual study samples (in this case, test instances) may lead to differences in the standard errors that can impact study results (Hanley, 2003; Sainani, 2010). Several mitigating factors may reduce the potential effect of clustering on these study results. The primary explanatory variable (patients who use one health system versus patients using more than one health system) was already partially aggregated to weight for the effect of patient clustering. Also, patient-level analysis of the incidence rate ratio of repeat test instances per patient remained significant. However, further analysis is required to fully account for the impact of health-system groups on study results.

Changes in the approach to care delivery resulting from the presence of an

accountable care agreement could influence study results. While agreement terms are confidential, under the agreement CHC-MN is increasingly accountable for the total cost of care of this patient population during the term of the agreement. As part of conducting this study, the author performed a complete review of the agreement to assess material terms or conditions that might impact study results. No material issues were identified.

CONCLUSIONS

While repeat test instances are valid for a number of clinical reasons, this study provides initial evidence that some portion of incremental test repetition among pediatric patients results when a patient visits multiple health systems. This may be due in part to a lack of physician access to prior test results and may be potentially redundant. Further research is needed to examine the underlying etiology of repeat test instances by examining the impact that test order location and individual test type has on these results. Research is also needed to better understand the impact that hospital policy may have on the effectiveness of using accessible prior test results in practice. Quantifying the impact that access to prior clinical results has on the incidence of repeat test instances, as well further identifying the barriers to improved information sharing, can assist policymakers in defining clear benefits to health information technology solutions such as health information exchange. Accessibility to prior test results enabled through a common electronic health record or through health information exchange may prove an important mechanism in efforts to promote safe and efficient delivery of healthcare by reducing the incidence of unnecessary repeat test instances.

REFERENCES

For references, see the dissertation bibliography section.

ARTICLE #2: EFFECT OF FACILITY TYPE ON THE RISK OF REPEAT TEST INSTANCES IN A PEDIATRIC POPULATION

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Running head: electronic health record use and repeat test instances by facility type

Key words: health care delivery, population health management, children's hospitals, test repetition

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SUMMARY

Background

Recent study results indicate that the odds of repeat test instances increase in a pediatric population that receives care from more than one health system than when treatment is provided within a single health system with an accessible electronic health record. Meaningful variation was found in the odds of test repetition by facility type with the risk of test repetition higher in hospitals than in outpatient, primary care or other facility settings. Higher test repetition levels in hospitals were consistent with findings in adult populations. The purpose of this study is to characterize the impact that facility type has on the association between patients receiving care from more than one health system and repeat test instances. These findings can support population-based research into the benefits of health information technology, including health information exchange, designed to improve care quality and lower the cost of medical testing.

Methods

A retrospective cross-sectional design was used to measure repeat test instances by facility type. The study population consisted of a continuing Medicaid population cohort of 12411 children (n=9128 patients with at least one test (66494 tests)) defined under a three-year demonstration project agreement between Children's Hospitals and Clinics of Minnesota (CHC-MN) and the Minnesota Department of Human Services (DHS) from 2012 to 2014. The study setting included all healthcare service organizations in the state of Minnesota that delivered health services to the defined study population and were reimbursed for services by the DHS under Medicaid. The study period was a one-year time frame ending September 30, 2013. Regression methods were used to test for significant associations between the outcome variable, repeat test instance, and the primary explanatory variable, patient health system use..

Results

This study confirmed that facility type has a significant impact on the risk of repeat test instances with inpatient care associated with higher risk of test repetition than outpatient and primary care settings. Comparing same facility pairs, within inpatient facility types, a significantly lower risk of repeat test instances was observed when the health system differed [OR 0.58 (95%CI: 0.45-0.74)]. This may be due to a single tertiary care hospital dominating the repeated tests in this category. Within outpatient facility types, no significant difference was observed when the health system differed. Within primary care facility types, higher odds of repeat test instances was observed when the health system differed [OR 1.32 (95%CI:1.18-1.47)].

Conclusions

Facility type has a significant impact on the risk of repeat test instances and may act as a surrogate measure for care intensity. Examining repeat pairings by same facility type, the health system effect remained evident in primary care settings suggesting that patients receiving primary care from more than one health system, presumably without access to prior test results, have an increased risk of repeat test instances. These results provide preliminary evidence of the potential benefits of leveraging health information technology, including health information exchange, in primary care settings.

BACKGROUND

Repetition by clinicians of the same or similar tests with a given patient is common (Bates, 1998b; Van Walraven, 1998). Repeat testing occurs for a number of reasons. A particular test may require multiple instances to obtain useful information. A particular disease or treatment may requires multiple results to obtain a clear understanding of disease progression or the impact of a health intervention over time. An initial test result is unclear or inconclusive requiring a repeat test. Risk factors that influence the level of repetitive testing include: patient demographic factors (including age, sex, race); test-related factors (including the purpose of the test, the test type and test accuracy); the nature of the condition being studied (including disease type, disease severity, presence of comorbidities particularly chronic conditions); and other factors including the location of care and the passage of time (Van Walraven, 2003; Zhi, 2013). Studies on the incidence of repetitive testing in children are sparse. Yet, evidence suggests that both repetitive testing patterns may vary substantially by age (Van Walraven, 2003).

Not all repeat tests are necessary or appropriate for care resulting in meaningful levels of both overtesting and undertesting. Inappropriate testing may result from failing to administer either index or repetitive tests when such tests are warranted, for screening, diagnosis or treatment purposes (undertesting or missing tests). Inappropriate testing may result from administering index or repeat tests that are not required for necessary or appropriate care (often noted as redundant or excess testing) (Zhi, 2013).

Overtesting is problematic for several reasons. First, overtesting is an indication of substandard patient care given the near term potential physical impact that testing has on the patient. Tests that are deemed to be unnecessary can create undue patient hardship resulting from test administration, particularly among children. Second,

increased test utilization increases the risk of false-positive tests that may impact patient well being. Third, increased false-positive results can also give rise to the "Ulysses syndrome" which is defined as the tendency towards complete and aggressive work-ups to identify the health status and treatment plan for a patient who does not in fact have the disease. This results in unnecessary economic cost associated with both administering the test as well as future medical costs for unnecessary downstream treatment (Rang, 1972; Dorevitch, 1992). Physician ordering practices, including panel-based ordering, lab order sets, and defensive medicine are primary drivers of overtesting (Epstein, 1986; Williams, 1982; McGillvray, 1993; Bugter-Maessen, 1996; Griffith, 1997; Mello, 2010).

Examining patient testing from a population-based perspective across all care settings, one source of overtesting may result from a lack of clinician awareness of prior test results performed at other health care locations or by other clinicians. Because patients commonly receive care across multiple health settings or health systems with different EHRs, providers often lack access to a patient's prior test results and reorder tests that would not be necessary if the prior test results were accessible. Without a mechanism for sharing prior test results, clinicians in this situations may repeat tests.

Limited evidence suggests that an electronic health record (EHR) may reduce redundant testing by clinicians, including lab and radiology tests, by making previous test results accessible (Bates, 1999). One broad objective of federal subsidies to promote investments in electronic health record technology, including Stage 3 meaningful use objectives, is to promote improved sharing of patient information, including test results, across health systems (HHS-ONCHIT, 2014). This objective is based upon the view that improved care coordination including information sharing leads to better health outcomes and lower healthcare costs, though results of such efforts remain mixed (Van Walraven, 2006; AMA, 2009; NQF, 2011).

Earlier research examining the odds of repeat test instances by facility type found meaningful variation in the odds of test repetition with the risk of test repetition higher in hospitals than in outpatient, clinic or other care settings (Knighton, 2014). Higher repetition levels for tests performed in a hospital were consistent with findings in adult populations and results in large part from variations in care intensity among different health care settings or facility types (inpatient, outpatient, primary care and other facility types) (Valenstein, 1988; Bates, 1998b; Van Walraven, 2003). Variation then in facility type may mask the true effect of multiple health system use on the risk of repeat test instances. The working assumption for this study is that facility type is a surrogate measure for care intensity with higher care intensity environments such as inpatient settings associated with a higher risk of test repetition. By measuring the risk of repeat test instances by facility pairs, better characterization of the effect that using multiple health systems has on the risk of repeat test instances in certain healthcare settings can be observed. Understanding the effect by facility type can aid in targeting tangible opportunities to improve quality and lower cost of medical testing from EHR deployment and health information exchange. IRB approval for this study was obtained from the Minnesota Department of Human Services (IRB# 280), Children's Hospitals and Clinics of Minnesota (IRB# 1402-022) and the University of Minnesota (IRB# 1403E49003).

METHODS

Several constructs were used for purposes of the study. A "**test instance"** was the unit of analysis for this study defined as any medical test performed by a clinician in a home care, primary care, outpatient, emergency room, inpatient, nursing home or other public health setting to provide information on a patients health status for screening, diagnosis, treatment or monitoring purposes. "**Repeat test instances"** were defined as a second lab or radiology test that follows a preceding instance of the same

test (index test) for the same patient during the study period. This required an exact match of the index test and repeat test CPT code. This approach precludes the matching of tests based upon the presence of test result information that may be available through related but different tests or through test panels. A "**pair or pairing"** is a combination of an index and repeat test instance of the same facility type. "**Probability of repeat test instances"** was defined as the probability that multiple instances of the same test are performed on the patient during the study period defined and was calculated as the count of repeat test instances divided by the test count. A **"health system"** was defined as a single network of clinics, hospitals, specialty programs and long-term care facilities under a common ownership structure designed to deliver health care. An important characteristic of single health systems in this study population is the presence of a distinct electronic health record system in each health system containing all information regarding patient care delivered within that health system (MDH, 2013 a,b). For purposes of this study, **"accessible prior test results"** were deemed accessible to the clinician via a common electronic health record if the patient received care from a single health system**. A "redundant test"** is defined based upon Bates criteria as "tests that follow other tests of the same type, can be prospectively identified and have little chance of yielding clinically important information" (Bates, 1998b). Identification of a redundant test typically requires that you have complete patient information, including the actual test values of index and repeat tests to correctly classify a test as redundant. In population-based studies in the United States, test information is captured decentrally within individual health system making collection of test results impractical..

Facility type was defined as the healthcare location that ordered the test. In this study four primary facility types were examined – inpatient, outpatient, primary care and other facility type. Facility type was classified based upon the defined algorithm

presented below. Two existing claims fields were used in classifying test orders based upon their source using administrative data:

1. Place of Service (POS) is an existing classification structure used by Medicaid for billing purposes to identify the physical location where the services were delivered.
2. Bill type is an existing classification structure used by Medicaid that includes the physical location of service, primarily for hospital billing purposes. Bill type is a four-digit identifier with each digit having a specific value. The first digit identifies the physical facility type (hospital, clinic, home health, etc.), the second identifies more specific facility designation and the third digit identifies the nature of the billing itself. This designation is useful primarily for further classification of items that do not have a place of service code.

From this, the following classification structure was developed as noted in Table 12 for classifying test instance by facility type.

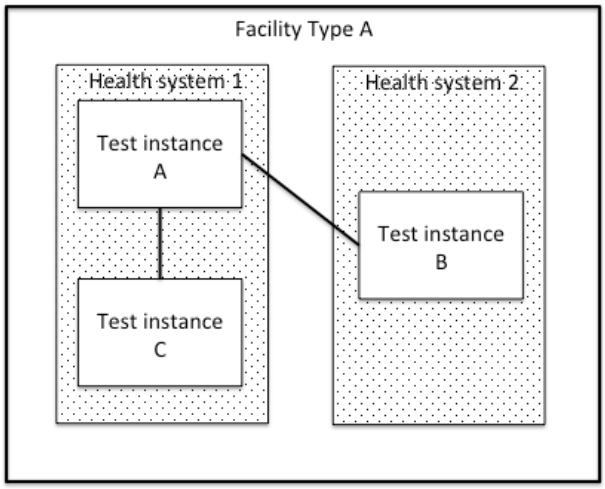
Table 12. Identification algorithm for test instance by facility type

Facility type	Description
Inpatient	• Test instances associated with a POS 21 code (inpatient hospital) • Test instances associated with an encounter without a POS code but with a bill type of 851 (critical access facility)
Outpatient	• Test instances associated with POS 22 (outpatient hospital) • Test instances associated with an encounter without a POS but with a bill type of 131, 141 and 831 (regular outpatient, outpatient diagnostic and ambulatory surgery centers, respectively • Test instances associated with POS 23 (emergency room) • Test instances associated with hospital/renal care with no POS but with bill type 721
Primary care	• Test instances associated with a POS of 11 (office visit) • Any test instance associated with an encounter with a bill type of 7 (clinic) • Any test instance associated with POS 20 (urgent care)
Other facility types	• Includes all test instances coded with another classification

"Other facility type" included a mix of different facility types, including schools, public health agencies and other community providers. This classification allows not only for repeated testing within facility type but also across quite different facilities within the category. Since the focus of this paper is to examine the impact of same versus different health systems within facility type, the "Other facility type" was not included in the examination of these effects.

Study objectives included measuring the risk of repeat test instances by facility type – inpatient, outpatient, primary care and other facility type categories. Further the potential effect multiple health system use would have on the risk of repeat test instances for three facility types – inpatient, outpatient and primary care was separately measured. A simplified model of the relationships is noted in Figure 5.

Figure 5. Model of index and multiple test instance pairings for a given facility type.



A retrospective cross-section design was used to conduct the analysis. The study population included a Medicaid total population cohort of 15886 children defined under a three-year demonstration project agreement between Children's Hospitals and

Clinics of Minnesota (CHC-MN) and the Minnesota Department of Human Services (DHS) from 2012 to 2014. CHC-MN is part of a distinct class of hospitals known as children's hospitals that exist to exclusively serve the needs of children and adolescents. Children's hospitals are characterized by expertise in treating children, including children with rare diseases, and in providing greater attention to psychosocial support for children and families.

Patient attribution to the Medicaid patient cohort was based upon Medicaid enrollment status and whether the patient received a plurality of primary care through CHC-MN. Patient attribution for purposes of this study was measured as of December 31, 2013. All test instance activity for the previous 12 months ending September 30, 2013 was included in the data files and analyzed. For purposes of this study, all patients that did not remain on Medicaid for the complete period of the study were excluded.

Examining outpatient test instances, a subset of renal patients (n=25) responsible for a high level of appropriate test repetition associated with scheduled renal dialysis routinely performed in a distinct health system's dialysis facility were removed. These test instances were removed for analysis purposes out of concern that they would impact the ability to detect repetition associated with more random testing patterns across the population. The final study population cohort included 12411 patients (9128 patients having at least one test) generating 66494 test instances.

The study setting includes all healthcare service organizations in the state of Minnesota that delivered health services to the defined study population and were reimbursed for services by the Minnesota Department of Human Services under the Medicaid program. Care settings included hospitals, emergency rooms, medical centers, outpatient and primary clinics, nursing homes and other long term care facilities, transportation assistance, public health agencies and other non-profit organizations. CHC-MN and its primary and specialty care network affiliates included in the

demonstration project provided approximately 30% of the total health service costs to the study population. CHC-MN and its network affiliates accounted for approximately 70% of test order volume in the population.

EHR adoption is high within the provider population serving study patients. The 2013 e-Health Survey conducted by the Minnesota Department of Health notes that 87% of clinics and 96% of hospitals, labs and local health departments have adopted electronic health record technology or equivalent HIT (MDH, 2013 a,b). The Department of Human Services provided patient and submitted claims data for all covered care paid by Medicaid and provided to the patient cohort, including claims submitted by healthcare organizations or radiology and lab services, for testing purposes. EHR utilization data was provided by the Minnesota Department of Health.

The unit of analysis was the test instance. The outcome variable was a binary variable identifying the instance as a repeat test instance (0/1). Potential adjusting risk factors were identified based upon known and potential patient, physician and test factors that may impact repeat test instances in adult populations including patient demographics (age, sex and residence); patient health status (number of chronic conditions, general health status, number of health systems used and total patient test volume); and approach to care (facility type, test type) (Van Walraven, 2003; Zhi, 2013; Knighton, 2014). Patient general health status was measured by the resource utilization band classification system devised using the Johns Hopkins ACG system (Johns Hopkins, 2009). The ACG system was designed to measure multi-morbidities and has been shown to have a strong correlation with overall patient health (Starfield, 2011).

Use of a single health system was defined as a binary (patient use of one health system for care or patient use of more than one health system for care). An important characteristic of a single health system is the presence of a single electronic health record that contains all patient data. Services by clinicians were based upon the national

physician identifier (NPI) code for the provider receiving payment for services (n=447). Instances were then individually reviewed and grouped by health system (n=292 health systems), each with a unique electronic health record instance. Univariate and multivariate logistic regression were deployed to test for significant associations between explanatory variables and the outcome variable.

RESULTS

The general characteristics of the population are noted elsewhere (Knighton, 2014). Summarizing the repeat test instances in this population, the majority of repeat test instances were consistently within the same facility type as the index instance, with the percentage ranging from 48.10% for other facility types to 90.99% for outpatient care as noted in Table 13.

Table 13. Proportion of repeat test instances by index facility type

	Repeat test instance facility type				
Index facility type	Inpatient	Outpatient	Primary	Other	Total
Inpatient	79.94%	16.21%	1.52%	2.33%	100.00%
Outpatient	1.48%	90.99%	6.01%	1.52%	100.00%
Primary care	0.26%	23.56%	73.74%	2.44%	100.00%
Other facility type	2.54%	35.56%	13.81%	48.10%	100.00%

Total test instances involving inpatient, outpatient and primary care and other facility type pairings with the same facility type were 66494 with 15456 of these repeat test instances for an overall risk of repeat test instances of 23.24% as noted in Table 14. Examining test volumes by index facility type**,** the significant majority of test instances were performed in outpatient settings (72.91%) followed by primary care settings (20.75%). Hospitals generated a small portion of total test transactions in this sample

(2.49%) but had an observed repeat risk that was about two times the risk of the other three facility types in the study 47.59% versus 22.62% for the remaining population).

Table 14. Risk of repeat test instances by index facility type – pairing same facility

Index facility type	Total test instances	%	Repeat test instances	%	Risk of repeat test instances
Inpatient	1658	2.49%	789	5.10%	47.59%
Outpatient	48484	72.91%	11769	76.15%	24.27%
Primary care	13795	20.75%	2595	16.79%	18.81%
Other facility type	2557	3.85%	303	1.96%	11.85%
Total	66494	100.00%	15456	100.00%	23.24%
Total Non-Inpatient	64836	100.00%	14667	100.00%	22.62%

To understand the effect of facility type on the association between health system use and risk of multiple test instances, the index facility type was stratified to examine the odds of repeat test instances when the pair is the same facility type. The multivariate logistic regression models within each facility type where both the index test and repeated test were generated from the same facility type are noted in Table 15. Significant covariates associated with the risk of repeat test instances in each model included age, residence, patient health status, health plan type and overall patient test count with some variation in significance level by facility type pairing.

With inpatient facilities, the odds of repeat test instances were lower when the subsequent test instance was from a different health system [adjusted OR 0.58 (95% CI: 0.45-0.74)]. Within the outpatient facilities, health system status did not have a significant effect [OR 1.04 (95% CI: 0.99-1.09)]. Within the primary care facilities, the effect of different health systems increased the odds of multiple tests instances [OR 1.32 (95% CI: 1.18-1.47)].

Table 15. Multiple logistic regression analysis of risk of repeat test instances within facility type

	Inpatient				Outpatient				Primary care			
Attributes	Odds ratio	P-value	95% CI		Odds ratio	P-value	95% CI		Odds ratio	P-value	95% CI	
Health system (different)	0.58	<.001	0.45-0.74	*	1.04	0.15	0.99-1.09		1.32	<.001	1.18-1.47	*
Sex (male)	0.86	0.16	0.69-1.06		0.99	0.63	0.94-1.03		1.04	0.38	0.95-1.14	
Age (in years)	0.97	<.001	0.95-0.98	*	1.01	<.001	1.01-1.02	*	0.99	0.01	0.98-0.99	*
Residence (urban)	0.72	0.007	0.57-0.92	*	0.97	0.33	0.92-1.03		0.87	0.004	0.79-0.96	*
Patient health status level:												
1 (Ref)	-	-	-		-	-	-		-	-	-	
2	0.04	0.002	0.01-0.29	*	1.93	<.001	1.43-2.61	*	1.85	<.001	1.38-2.47	*
3	0.12	<.001	0.06-0.23	*	2.86	<.001	2.13-3.84	*	2.20	<.001	1.66-2.92	*
4	0.22	<.001	0.15-0.31	*	3.96	<.001	2.94-5.33	*	2.41	<.001	1.78-3.26	*
5	-	-	-	**	4.57	<.001	3.37-6.20	*	2.44	<.001	1.70-3.51	*
Chronic condition count	1.00	0.971	0.96-1.03		1.00	0.81	0.99-1.01		0.97	0.09	0.94-1.00	
Health plan type	0.55	<.001	0.41-0.75	*	1.00	0.88	0.95-1.06		1.24	<.001	1.11-1.40	*
Patient total test count	1.00	0.461	0.99-1.00		1.01	<.001	1.01-1.01	*	1.01	<.001	1.01-1.01	*
Intercept	3.41	<.001	2.23-5.24	*	0.05	<.001	0.04-0.06	*	0.08	<.001	0.06-0.11	*

*Significant at 0.05
**9 test instances not used due to collinearity

DISCUSSION

Facility type has a significant impact on the risk of repeat test instances. Inpatient care is associated with higher risk of test repetition than outpatient and primary care settings (Valenstein, 1988; Bates, 1998b; Van Walraven, 2003). The study confirmed similar findings in a pediatric population. The working assumption for this study was that differences in repeat testing by facility type is due to care intensity with higher care intensity environments such as inpatient settings associated with a higher risk of test repetition. Higher intensity settings such as tertiary care hospitals are characterized by higher volumes of services for a given patient encounter. Understanding the effect of facility type on patients using more than one health system and the risk of repeat test instances allows for better characterization of the potential effect that multiple health system use (and presumably accessible prior test results) may have on the risk of repeat test instances. Understanding the effect by facility type can aid

in targeting tangible opportunities from EHR deployment and health information exchange to improve quality and lower cost of medical testing.

In this study inpatient facilities had the highest risk of repeat test instances (47.59%). That high risk may be explained at least in part by the high-intensity nature of care given in inpatient settings for acute patient conditions. Physician ordering practices in the treatment of acute conditions include the use of panel-based ordering, standard inpatient order sets associated with standard workflows to monitor patient status (Mello, 2010; Epstein, 1986; Williams, 1982; McGillvray, 1993; Bugter-Maessen, 1996; Griffith, 1997). As this study reports, the highest percentage of repeated tests occurred in inpatient facilities with approximate half that rate occurring in outpatient and primary care settings. This further suggests that when analyzing repeat test instances, facility type may be a surrogate measure for care intensity and important risk factor.

By examining only within inpatient facility pairings (in effect, eliminating the impact of differential care intensity across facility types on risk of repeat test instances), patients receiving care in more than one health system had a significantly lower risk of repeat test instances than patient receiving all care within the same health system [adjusted OR 0.58 (95% CI: 0.45-0.74)]. One explanation for this finding may come from understanding the underlying patient population. Children who receive care at children's hospitals such as CHC-MN are generally more infirm, with greater risk of multiple comorbidities, chronic conditions and more severe medical needs than children receiving inpatient care at other hospitals included in this study's data (Meurer, 1998; Merestein, 2005). Over 80% of the inpatient repeated test pairs were within CHC-MN; a tertiary care facility with a higher intensity of care As a result, risk of repeat test instances within the same health system may be higher in this study population because patients that are sicker, with more chronic comorbid conditions, are more likely to return to CHC-MN for care rather than another non-CHC-MN facility. A population of children with more severe

comorbid conditions is more likely to require ongoing medical testing during the period of study. This was supported by the regression analysis that demonstrated that the likelihood of a repeated test instance was positively related to the severity ranking of the patient's health.

Another explanation may arise from the fact that a majority of inpatient care in this study population was delivered by a single children's health system (CHC-MN). The risk of repeat test instances may be higher in CHC-MN due to physician and hospital practices regarding the use of medical testing. Health information technology enables innovation but only to the extent that HIT availability aligns with the human decision-making needs of an organization. Evidence suggests that physicians will seek information but only if its deemed to be relevant to the decision at hand, reliable in terms of information quality and timely (Andrews, 2005; Coumou, 2006). For example, clinicians may have accessible test results within an EHR but still elect to repeat tests as a matter of preference. That preference may be based on the perceived relevance and reliability of the test data and/or health system policy that encourages clinicians to repeat tests using only health system resources.

Finally, another potential explanation may be that there is some other confounding factor associated with both availability of prior test results and health system use in inpatient-inpatient pairings that is impacting results. Additional data regarding the risk of repeat test instances when pairing inpatient instances with non-inpatient instances was not available but may prove useful in better explaining this particular finding.

Outpatient index test instances were the most common type (72.91%) due to the volume of outpatient activity within this particular patient population. Risk of repeat test instances was lower in outpatient types (24.27%) than inpatient settings. Lower risk was due at least in part to the nature of conditions treated in an outpatient setting and the

resulting lower intensity of care provided to treat these conditions which impacts the need for repeat test instances. The study revealed a higher, though only marginally significant risk of repeat test instances [OR 1.04 (95%CI:0.99-1.09)] when patients used more than one health system. This may suggest that a large portion of the significant difference in risk of a multiple test is associated with facility type (and by extension potential differences in intensity of care by facility type mentioned earlier) and may not be a result of lack of access to prior test results in outpatient facilities.

Primary care index test instances were the second most common type (20.75%). Risk of repeat test instances in primary care facility types was lower (18.81%) than in inpatient or outpatient settings. This may be due at least in part to the nature of conditions treated in a primary care settings and the resulting lower intensity of care provided to treat these conditions. Similarly, the number and type of tests (both lab and radiologic) are also more limited in these settings. Within the primary care facility type, the study revealed a significantly higher risk of repeat test instances [OR 1.32 (95%CI:1.18-1.47)] for multiple health system use. This suggests that the availability of prior test results in primary care settings may have potential to lower medical test utilization by making prior test results available to clinicians via an electronic health record or health information exchange.

LIMITATIONS

There are limitations to these study results. The cohort being studied is based upon an attribution formula that assigns patients to the ACO based upon (1) participation in a complex care coordination program in place (selection of CHC-MN to receive care) and (2) plurality of care given at a children's hospital/clinic. Given that patients can elect where they receive a majority of their care, patients in effect self-select to the attributed population. This may impact the generalizability of external validity of the study results.

Children's hospitals have a set of potentially distinct characteristics from general hospitals including the setting, patient demographics, the nature and severity of conditions treated and distinct protocols or pathways in place [Meurer, 1998; Merestein, 2005]. Similarly, selection to the study cohort is based upon an attribution formula discussed earlier. Under this attribution formula, patients are included in the cohort based upon receiving a plurality of primary care from CHC-MN and by extension, its specialty, outpatient and inpatient services. Care should be taken in applying these results across a general pediatric population.

Limitations in the secondary use of Medicaid claims data for research are cited by some as problematic when it comes to claim accuracy and the lack of clinical specificity with regards to diagnoses and underlying test results (Hsia, 1988; Seiber, 2007; Chisholm, 2009; HHS-CMS, 2013). Standard audit processes for testing Medicaid claims error rates occur annually. The PERM (Payment Error Rate Measurement program) is sponsored by CMS and involves state evaluations on a rolling three-year test cycle. As of the 2010 test cycle (which includes Minnesota), the national error rate for payment was 1.89% +/- 0.62%. (range from 1-3%). State results range from 0.6 to 3.8%. Overall, Medicaid views these national results optimistically suggesting that no systemic problems exist in the results (Chisholm, 2009). Enrollment continuity, often cited as a problem in using Medicaid data, was addressed by limiting the population to those patients who were enrolled for at least 12 months (Crystal, 2007). Regarding the lack of complete information, such limitations are more a function of the nature of the study being conducted than of the underlying limitations of the data (Dumbkowski, 2012; Cooke, 2013). For purposes of this evaluation, the population-based approach to this study should limit the effect of limitations in the use of Medicaid claims data on the results of the study.

The statistical methods used for this study do not fully address the impact of correlated data on study results. Naturally occurring groups such as patients and health systems may have more similar observations than different groups. The lack of independence between individual study samples (in this case, test instances) may lead to differences in the standard errors that can impact study results (Hanley, 2003; Sainani, 2010). Several mitigating factors may reduce the potential effect of clustering on these study results. The primary explanatory variable (patients who use one health system versus patients using more than one health system) was already partially aggregated to weight for the effect of patient clustering. However, further analysis is required to fully account for the impact of correlated data on study results.

Changes in the approach to care delivery resulting from the presence of the accountable care agreement could influence study results. While agreement terms are confidential, under the agreement CHC-MN is increasingly accountable for the total cost of care of this patient population during the term of the agreement. As part of conducting this study, the author performed a complete review of the agreement to assess material terms or conditions that might impact study results. No material issues were noted.

CONCLUSIONS

Facility type can have a significant impact on the risk of repeat test instances and may act as a surrogate measure for care intensity. The rates of such instances vary substantially among facility types. Furthermore, within the primary care facility type, the health system effect remained, suggesting that patients receiving care from more than one health system using separate electronic health records systems impacts the risk of repeat test instances. Further research is needed to understand this effect when patients move between facility types. These results provide preliminary evidence of the

potential benefits of leveraging health information technology, including health information exchange, to lower test utilization and improve quality of care in pediatric populations.

REFERENCES

For references, see the dissertation bibliography section.

ARTICLE #3: EFFECT OF AN ACCESSIBLE ELECTRONIC HEALTH RECORD ON THE INCIDENCE OF PROBLEMATIC REPEAT LEAD TESTING IN A PEDIATRIC ACCOUNTABLE CARE POPULATION

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Running head: electronic health record and repeat lead testing

Key words: lead testing, health care delivery, population health management, children's hospitals, test repetition, electronic health record

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SUMMARY

Background

Evidence exists that a substantial number of medical tests may be redundant. One identified source of potential redundancy may come from a lack of access to prior test results available through an accessible electronic health record (EHR) when patients move between health systems. In Minnesota, lead testing in children is performed by a mix of healthcare organizations and public agencies. No queryable central information repository exists for sharing patient lead test results among these organizations. The objective of this study is to determine whether patients receiving care from more than one health system is associated with repetitive lead testing in children. Repeat testing may be due in part to a lack of clinician access to prior screening or diagnostic test results, making the repeat test necessary but potentially redundant or inconsistent with recommended patterns of care. If so, then access to a common electronic health record or queryable information solution may lower the incidence of certain lead test repetition.

Methods

A retrospective cross-sectional design was used to measure initial and repeat test instance pairs. The population-based study consisted of a Medicaid population cohort of 12436 children (n=1856 patients with at least one lead test) defined under a three-year demonstration project agreement between Children's Hospitals and Clinics of Minnesota (CHC-MN) and the Minnesota Department of Human Services (DHS) from 2012 to 2014. The study setting included all healthcare service organizations in the state of Minnesota that delivered health services to the defined population and were reimbursed for services by the DHS under Medicaid. Criteria for identification of problematic repeat lead testing

was based upon review of literature and discussions with CHC-MN clinicians. Logistic regression methods were used to test for significant associations.

Results

A total of 2069 lead test instances were identified. Overall test repetition during the study period accounted for 10.29% (213 repeat tests) of the total lead test instances. Based upon criteria developed, approximately 50% of the repeat tests in this study were identified as problematic, representing 5.12% of the lead tests performed on this population in one year. Separately it was noted that 35.0% (n=955) of eligible children did not receive at least one lead test. Repeat tests performed in different health systems on different EHR platforms than the initial tests were 6.49 times more likely [adjusted OR 6.49 (95%CI: 2.825-14.925)] to be problematic than if the repeat and index test were performed within the same health system with a single accessible electronic health record.

Conclusions

A significant portion of repeat lead testing may be problematic. Use of a single health system with prior lead test results accessible through a common electronic health record significantly impacts the level of problematic testing performed. Introduction of accessible prior test results through a single queryable information repository, or through the exchange of health information, may reduce problematic lead testing. Future Medicaid accountable care agreements between the state Medicaid program and participating health systems should include clear population accountability for performing lead or other test screenings to improve patient safety and lower the cost of care.

BACKGROUND

Medical testing, including laboratory and imaging tests, is costly with an estimated 4.3 billion tests performed in the US annually at a cost of $65 billion (Alexander, 2012). Evidence exists that a substantial number of these tests may be redundant (Van Walraven 1998; Bates, 1998b). One source of potential redundancy may come from a lack of access to prior test results available through an accessible EHR when patients move between health systems (Thomas, 2000; Van Walraven, 2006; Gupta 2010). Previous study results suggest that the odds of repeat test instances of the same test increase for pediatric patients that receive care from more than one health system (Knighton, 2014).

One area of current interest is the use of lead tests for the screening, diagnosis and monitoring of elevated blood lead levels (EBLLs) in children. Today at least 4 million households have resident children that are being exposed to high levels of lead (HHS-CDC, 2014c). While any level of lead in the blood is potentially harmful, approximately half a million U.S. children ages 1-5 have blood lead levels above 5 micrograms per deciliter (mcg/dL), the reference level at which the CDC recommends interventions be initiated to lower EBLLs (HHS-CDC, 2014b). This level is based on the population of children between the ages of 1 and 5 years in the U.S. who are in the top 2.5% of children when tested for lead in their blood. Nationally, over the past ten years, an average of 3.7 million children were tested annually (HHS-CDC, 2014c). In the State of Minnesota in 2012, approximately 2600 children were identified as having EBLLs with 255 confirmed cases with EBLL>10µg/dL. This represents 3.06% of the population tested and 0.6% of the population of children in Minnesota less than 72 months old (MDH, 2013c; HHS-CDC, 2014c).

Some repeat testing is required to properly screen, diagnose, treat and monitor patients for EBLLs. Medicaid guidelines require that all Medicaid recipients be tested for

elevated lead levels at 12 and 24 months of age as part of an effective screening program. This policy is due to risk factors associated with elevated lead levels in children on Medicaid, including lower socioeconomic status associated with living in older homes with lead exposure (HHS-CMS, 2014a). Children between the ages of 36 and 72 months should also be screened if they were not screened at 12 and 24 months (Wengrovitz, 2009).

Two methods of test administration exist for screening, diagnostic and/or monitoring purposes. The first method is for screening purposes is a capillary test and uses a point of care instrument that takes a finger prick sample. This method is most commonly used in physician offices, schools, Women, Infants and Children (WIC) clinics and other public health organizations. Test results are available within 3 minutes and can measure a range between 3.3mcg/dL and 65mcg/dL with reasonable accuracy. Retesting guidelines using a confirmatory venous test vary from >5-10mcg/dL for elevated capillary test results. A venous lead test may also be administered as the primary screening method. A venous test is considered conclusive (gold standard) in the diagnosis and monitoring of elevated blood lead levels (EBLLs) and is used as a confirmatory test following an elevated capillary test (ACCLP, 2013). Immediate actions to remove the environmental sources of lead contamination can lower EBLLs. (HHS-CDC, 2014a) Recommended care interventions and retesting guidelines based upon initial screening results are noted in Table 16.

Table 16. Recommended care interventions and rescreening guidelines by care intervention result (HHS-CDC, 2014a)

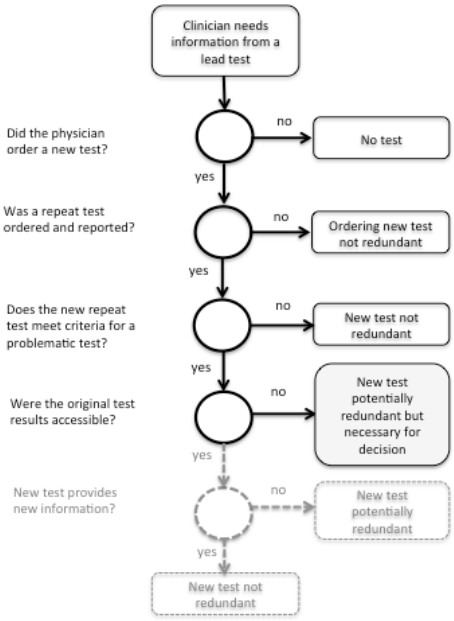
Test Result	Intervention	Retesting Guidelines
<5µg/dL	None	Rescreen in 12 months
>5µg/dL	Caregiver efforts to examine surroundings to identify and remove any sources of lead contamination	Retest in 3 months
>15µg/dL	Engagement of a state lead risk assessor that perform an environmental review of the child's residence to find and eliminate hazards	Retest in 1-3 months
>20µg/dL	Engagement of a state lead risk assessor that perform an environmental review of the child's residence to find and eliminate hazards	Retest in 2-4 weeks
>45µg/dL	Medical attention	Immediate
>60µg/dL	Emergency medical attention, potentially including the use of chelation therapy to lower blood lead levels	Immediate

A 2012 national expert committee report updating new EBLL guidelines also encouraged efforts to facilitate data sharing between health care providers and agencies in an effort to efficiently screen and monitor at-risk children (HHS-CDC, 2012). In Minnesota, screening and diagnostic testing for lead is performed by a mix of non-profit agencies, public health organizations or specialty and inpatient health care providers. No central queryable information repository exists for sharing lead test results among these organizations. Electronic health record systems in provider organizations are the primary mechanism in place for the exchange of test results. Levels of actual electronic information exchange between separate health systems during the study period remained low when exchanging health information between health systems based upon a recent state survey data (MDH, 2013 a,b).

The hypothesis is that the lack of an accessible electronic health record or health information technology (HIT) solution among health care providers produces a level of repetitive testing that results from a clinician's lack of access to prior screening or diagnostic test results when patients visit more than one health system. Lack of accessible test results make repeat testing necessary but potentially redundant or inconsistent with recommended patterns of care as noted in Figure 6. If so, then access

to a common electronic health record or shared information solution should lower the incidence of certain repetition.

Figure 6. Identifying problematic lead testing in a pediatric population



To test this assumption, criteria were identified to differentiate appropriate test repetition from problematic repeat tests that may result from a presumable lack of clinician access to prior test results in a shared medical record. The difference in problematic repeat testing when the index and repeat test were performed within the same health system was compared against problematic repeat testing when the index and repeat test were performed in different health systems.

IRB approval for this study was obtained from the Minnesota Department of Human Services (IRB# 280), Children's Hospitals and Clinics of Minnesota (IRB# 1402-022) and the University of Minnesota (IRB# 1403E49003).

METHODS

The objectives of this study were to (1) characterize repeat lead testing within the pediatric population, (2) identify useful criteria to identify problematic repeat tests and then (3) compare the odds of problematic repeat testing between repeat tests performed by the same health system as the index test and repeat tests performed by a different health system than the index test. Criteria for identification of problematic repeat lead testing was based upon review of literature and discussions with internal clinicians at CHC-MN.

The following measurement constructs were defined for purposes of the study. A "**lead test instance"** was the unit of measure for this study and was defined as any medical test performed and invoiced via claim by a clinician in a home care, primary care, outpatient, emergency room, inpatient, nursing home or other public health setting to provide information on a patients health status for screening, diagnosis, treatment or health maintenance purposes. A "**repeat lead test"** was defined as a diagnostic, screening or monitoring test that follows a preceding instance of the same test (index test) for the same patient during the study period. Definition of a repeat test required an exact match of the index test and repeat test CPT code. Venous and capillary test types were not separately specified for purposes of matching index and repeat tests. The "**probability of test repetition"** was defined as the probability of a repeat test during the study period (repeat volume/total volume). Repeat counts were also aggregated by unique patient. **"Days to next test instance"** was defined as the number of days between the index test and the next test instance (next test instance date – index test date). A **"health system"** was defined as a network of clinics, hospitals, specialty programs and long-term care facilities under a common ownership structure designed to deliver care. For purposes of this study, **"accessible prior test results"** were deemed accessible to the clinician via a common electronic health record if the subsequent

medical test was ordered by a clinician operating within the same health system or health agency that ordered the index test. Use of the same health system was considered a reasonable proxy for accessibility given that each health system in Minnesota has its own common electronic health record shared by the individual health system locations. This was confirmed by reviewing Minnesota Department of Health data regarding EHR use (MDH, 2013 a,b).

"**Problematic repeat lead tests"** were defined as repeat tests with one or more characteristics that may suggest a higher risk of test redundancy. The definition of a problematic repeat test was based upon published clinical guidelines and discussions with physicians at CHC-MN. Patient age, test type, days between tests and diagnosis coding were used as characteristics to identify repeat test sequences that are inconsistent with recommended patterns of care and thus problematic as follows:

- Patients receiving three or more capillary tests within one year. The presence of the second capillary test implies that the first test was within normal levels. Otherwise, the patient should have received a venous test to confirm the diagnosis of EBLL. The presence of a third capillary test implies that the first two tests were within normal limits meeting the testing requirements. A third or fourth capillary test is problematic and would have a high probability of being redundant.
- Patients who received a base capillary test followed by a second base capillary test in less than 9 months. Performing a second base capillary test after an initial test reasonably implies that the first test results were normal. Guidelines suggest that sufficient time between the first and second test should be given to ensure that the second test has value for screening purposes.
- A capillary test that follows a venous test within 9 months. A capillary test following a venous test would imply that the initial venous test was normal (some care givers

give only a venous test for lead screening). Guidelines suggest that sufficient time between the first and second test exist to ensure that the second test has value for screening purposes.

- Repeat capillary test on any child <18 months old. A repeat capillary test would only be reasonable if the first test given at approximately 12 months of age was normal. Guidelines suggest that sufficient time between the first and second test exist to ensure that the second test has value for screening purposes.
- Repeat test within 90 days for a patient with no diagnostic indication of elevated blood lead levels in the index or repeat encounter based upon ICD-9 diagnostic coding. A listing of these conditions is noted in Table 17.

Table 17. Diagnoses, signs and symptoms associated with elevated blood lead levels by ICD-9 code (Aetna, 2014)

Diagnoses, Signs and Symptoms	ICD-9
Iron deficiency anemia	280.0 - 280.9
Pica	307.52
Specific delays in development	315.00 - 315.9
Hearing loss	389.00 - 389.9
Constipation	564.00 - 564.09
Coma	780.01
Transient alteration of awareness	780.02
Other convulsions	780.39
Other malaise and fatigue [lethargy]	780.79
Lack of coordination [ataxia]	781.3
Anorexia	783
Lack of expected normal physiological development in childhood	783.40 - 784.43
Headache	784
Nausea and vomiting	787.01 - 787.03
Abdominal pain	789.00 - 789.09
Toxic effect of lead and its compounds (including fumes)	984.0 - 984.9
Child neglect (nutritional)	995.52
Other child abuse and neglect	995.59
Accidental poisoning by lead paints	E861.5
Accidental poisoning by lead and its compounds and fumes	E866.0
Abandonment or neglect of infants and helpless persons	E904.0
Exposure to lead	V15.86

The study was a retrospective cross-sectional design. The population for this study was a Medicaid total population cohort of 15,886 children defined under a three-year, demonstration project agreement between Children's Hospitals and Clinics of Minnesota (CHC-MN) and the Minnesota Department of Human Services (DHS) running

from 2012-2014. CHC-MN is part of a distinct class of hospitals known as children's hospitals that exist to exclusively serve the needs of children and adolescents. Children's hospitals are characterized by expertise in treating children, including children with rare diseases, and in providing greater attention to psychosocial support for children and families.

Patient attribution to the Medicaid patient cohort was a based upon (a) Medicaid enrollment status and (b) whether the patient received a plurality of their care through CHC-MN primary care clinics. Patient attribution for purposes of this study was measured as of December 31, 2013. All lead test instance activity for the previous 12 months ending September 30, 2013 was included in the data files and analyzed. For purposes of this study, all patients that did not remain on Medicaid for the complete period of the study were excluded. The final study population cohort includes 12436 patients (9153 patients having at least one test). Of this population, 1856 received at least one lead test during the study period.

The study setting includes all healthcare service organizations in the state of Minnesota that delivered health services to the defined study population and received reimbursement for services by the Minnesota Department of Human Services under the Medicaid program. Settings include hospitals, emergency rooms, medical centers, outpatient and primary clinics, nursing homes and other long term care facilities, transportation assistance, public health agencies, other non-profit organizations and so forth.

CHC-MN and its primary and specialty care network affiliates included in the demonstration project provided approximately 30% of the total health service costs to the study population. CHC-MN and its network affiliates account for approximately 70% of test order volume. EHR adoption is high within the provider population serving study patients. The 2013 e-Health Survey conducted by the Minnesota Department of Health

notes that 87% of clinics and 96% of hospitals, labs and local health departments have adopted electronic health record technology or equivalent HIT (MDH, 2013 a,b).

The Department of Human Services provided Medicaid enrollment and claims/encounter patient data for all medical care paid by Medicaid and provided to the patient cohort. Lead test instances were coded for reimbursement purposes at least two ways, based upon the test type and how the test is administered and analyzed. Tests taken on site and analyzed locally from a Clinical Laboratory Improvement Amendment (CLIA) organization were generally coded as a single line item that includes both the cost of administering and analyzing the test (CPT Code – 83655). Tests taken by a health practitioner and then sent to another lab for analysis are coded as either CPT 36415 (venous) or 36416 (capillary).

For purposes of classifying lead test instances as either venous or capillary set criteria was used. Tests that were sent offsite were coded based upon the accompanying CPT code for test administration noted in the encounter. If tests that were coded as lead only with no administration (generally onsite tests), they were classified as venous if the test was performed at CHC-MN (their standard procedure for lead testing at CHC-MN is to take a venous draw), if another venous blood draw was taken during the same visit, or if results were directed to a lab. If none of these criteria were met, the test was identified as capillary. Claims data was coded by provider using the national provider identifier. For purposes of this study, all providers were categorized by health system as defined above.

Descriptive statistical methods were deployed to characterize the population and to identify potential risk factors for repeat test instances in children. The outcome variable was a binary variable identifying the repeat instance as a either a problematic or non-problematic repeat test instance (0/1). The principal explanatory variable of interest was binary and identified whether the location of the repeat test differed from the index

test. Other potential explanatory variables were identified for testing based upon previous work as well as known and potential patient, physician and test factors that could impact repeat test instances in adult populations including: patient demographics (age at start of study, age at time of test, sex and residence); patient health status (number of chronic conditions, general health status and total patient test volume); and approach to care (care location, test type) (Van Walraven, 2003; Zhi, 2013; Knighton, 2014). Patient general health status was measured by the resource utilization band classification system devised using the Johns Hopkins ACG system (Johns Hopkins, 2009). The ACG system was designed to measure multi-morbidities and has been shown to have a strong correlation with overall patient health (Starfield, 2011). Multivariate logistic regression was used to test patient characteristics associated with lead test repetition for significance and to measure the effect of common health system use on the incidence of repeat testing.

RESULTS

The patient population included 15887 patients attributed to the accountable care population as of December 31, 2113, of which 12436 patients were enrolled in Medicaid for the entire study period. As portrayed in Table 18, 1856 patients in the population (14.92% of the total population) had at least 1 lead test during the study period. A total of 2069 lead test instances were performed (venous – 58.82%; capillary – 41.18%) representing 3% of total test instances for the population. Mean age at start of study for children receiving at least 1 lead test was 1.82y (median 1.32y). Over 80% of patients receiving a lead test were between the ages of 0-4 at the time the test was administered. 47.35% of total patients (n=12436) within the overall study population between the ages of 0-4 received at least 1 lead test during the study period. Screening compliance (at

least one lead test performed) among the eligible children (age between 0 and 540 days at the start of the study period) was 64.99% (1114 tests/1714 eligible children). Reviewing patient instance/diagnostic data, no patients were identified as receiving chelation treatment during the study period (ICD 9: 984.0-984.9 – Toxic Effect of Lead and Its Compounds). Overall test repetition accounted for 10.29% (213 repeat tests) of the total lead test instances. Lead instance volume per patient during the study period ranged from 1-4 tests. Of the 213 repeat tests, 19.72% involved an index capillary test followed by a repeat capillary test. 26.76% involved an index capillary test followed by a repeat venous test (total index capillary tests n=99). Of the 213 repeat tests, 14.08% involved an index venous test followed by a repeat capillary test. 39.44% involved an index venous test followed by a repeat venous test (total index venous test n=114).

Using multivariate logistic regression to test patient characteristics significantly associated with problematic test repetition included age at visit [OR 0.69 (95%CI: 0.54-0.90)] and urban residence [OR 0.35 (95% CI: 0.16-0.78)] Most common observed index order locations for a repeat test included outpatient settings (49.29%) followed by primary care (42.7%) and public health (7.5%). A similar pattern existed for reorder locations with outpatient setting highest (62.4%) followed by primary care (33.33%) and public health (4.2%). Mean days to next test instance between the index and repeat test were 123d (median 95d). Stratifying by index test type between venous or capillary, observed time to repetition was longer for index venous tests (137d) than for index capillary tests (107d). A similar difference was found when examining repeat test types with observed venous mean test time to repeat (126d) longer than for capillary tests (118d).

Table 18. Study population characteristics – overall and for patients with at least one lead test

Characteristic	Categories	All patients	% Total	Patients with lead test	% Total
Patient Count	Total	12436	100.00%	1856	100.00%
Test Transactions	Total	68856	100.00%	2069	100.00%
Sex	Male	6503	52.29%	982	52.91%
Age (start of study - 10/1/2013)	Mean (median)	7.09 (6.22)		1.82 (1.32)	
	IQR	2.89 - 10.79		0.72 - 2.18	
	<1	1340	10.78%	645	34.75%
	1-4	3772	30.33%	1111	59.86%
	5-9	3726	29.96%	84	4.53%
	10-14	2550	20.50%	13	0.70%
	15-17	605	4.86%	2	0.11%
	18-20	443	3.56%	1	0.05%
Age (at time of visit)	Mean (median)	8.10 (7.10)		1.71 (2.0)	
	IQR	7.10 - 12.87		1-2	
	<1	934	7.51%	221	10.68%
	1-4	3620	29.11%	1714	82.84%
	5-9	4001	32.17%	117	5.65%
	10-14	2677	21.53%	15	0.72%
	15-17	637	5.12%	1	0.05%
	18-20	567	4.56%	1	0.05%
Residence by type	Urban	9278	74.61%	1449	78.07%
	Suburban/Rural	3158	25.39%	407	21.93%
Chronic condition count	0	7112	57.19%	1254	67.56%
	1	2833	22.78%	358	19.29%
	2	1124	9.04%	121	6.52%
	3	517	4.16%	42	2.26%
	4	316	2.54%	31	1.67%
	5+	534	4.29%	50	2.69%
Patient health status	1	1535	12.34%	147	7.92%
	2	3987	32.06%	551	29.69%
	3	5273	42.40%	954	51.40%
	4	1187	9.54%	140	7.54%
	5	454	3.65%	64	3.45%
Plan type	Managed care	9629	77.43%	1547	83.35%
	FFS	2807	22.57%	309	16.65%
Test type by transaction	Venous			1217	58.82%
	Capillary			852	41.18%
Lead tests per patient	1			1856	89.71%
	2			190	9.18%
	3			18	0.87%
	4			5	0.24%

The study results suggest that a level of problematic repeat tests exist when examining the study population. The level of repeat testing that is problematic is approximately 50% of the repeat population in this study. Results of the profile are noted in Table 19.

Table 19. Count of problematic repeat lead tests

Repeat lead tests	Count	% Problematic Repeat Tests	% Total Repeat Tests	% Total Test Transactions
An index capillary test followed by a repeat capillary test in less than 9 months	36	23%	17%	2%
More than two capillary tests during the study period	3	2%	1%	0%
A repeat capillary test that follows an index venous test within 9 months	28	18%	13%	1%
Repeat capillary test on any child <18 months old	21	13%	10%	1%
Repeat test within 90 days for a patient with no diagnostic indication of elevated blood lead levels in the index or repeat encouter based upon ICD-9 encounter coding	69	44%	32%	3%
Total Count of Repeat Tests Meeting Criteria	157	100%	N/A	N/A
Net Count of Repeat Tests Meeting Criteria (some test instances meet more than 1 critiera)	106	100%	50%	5%

Three types of inappropriate testing were identified through the study - excess tests that appear to be repeated more than necessary and tests taken too soon following the initial test thus limiting the test's informational value in care. This level of problematic lead testing indicates that 106 lead tests out of 2069 performed during the study period were problematic, representing 5.12% of the tests performed on this population in one year. The other form of inappropriate lead testing identified was undertesting. In a separate analysis, it was noted that 35.0% (n=955) of eligible patients in the population did not receive at least one lead screening during the study period. On an unadjusted and adjusted basis, repeat tests performed at different systems on different EHR platforms were 4.61 times more likely [95% CI: 2.58–8.26] and 6.49 time more likely [95% CI: 2.83-14.93] to be problematic, respectively, than if the repeat and index test were performed within the same health system on a common platform.

DISCUSSION

Test repetition is expected in lead testing for screening, diagnostic and monitoring purposes. Overall test repetition accounted for 10.29% (213 repeat tests) of the total lead test instances. Criteria for identifying problematic lead screenings was

proposed by examining characteristics of the test administration including child age, days between tests and the sequencing of tests administered to detect potential problematic repeat tests. Reasonable test sequences, consistent with evidence-based standards of care, provide evidence of an underlying process of care for screening, diagnosis and treatment. Evidence of seemingly random test patterns indicate a possible lack of coordination in patient care suggesting that a test is problematic and has a higher risk of being redundant..

The results suggest that 50% of repeat lead tests within this particular test population were problematic in that either the test appeared excessive or the repeat test was performed too soon after the index test instance, limiting its clinical value. When examining problematic repeat tests by health system, repeat test instances performed in a different health system than the index test instance using different EHR instances were 6.5 times more likely to be problematic than repeat transactions performed within the same system on a common EHR instance [95% CI: 2.83-14.93]

These results provide evidence regarding the hypothesis that the lack of an accessible electronic health record or queryable health information technology solution between health agencies and health care providers results in significantly higher levels of problematic repeat testing. Higher levels of repeat testing may be due to a clinician's lack of access to prior screening or diagnostic test results, making a repeat test necessary, but premature or potentially redundant, in providing an appropriate process of care.

The fact that each health system has a distinct electronic health record system makes it particularly difficult to separate the impact of accessible test results in an electronic health record from the effect of each health system's policies and practices on the incidence of repeat test instances. This difficulty gives rise to a potential alternative explanation of the results. Health information technology enables innovation but only to

the extent that HIT availability aligns with the human decision-making needs of an organization. Evidence suggests that physicians will seek information but only if its deemed to be relevant to the decision at hand, reliable in terms of information quality, and timely (Andrews, 2005; Coumou, 2006). For example, clinicians may have accessible test results from another health system but still elect to repeat tests, as a matter of preference given concerns regarding the relevance and reliability of the test data, or due to health system policy that encourages clinicians to repeat tests using only health system testing resources. The impact is that some portion of the incremental test repetition identified through this study may result from these mechanisms, making it difficult to estimate the effective impact that making prior tests results accessible through either a single electronic health record or through the health information exchange would have on the incidence of repeat test instances. Future study is required to separate the effect of health system policy from the impact of accessible prior test results on the level of repeat test instances.

An argument could be made that a level of unnecessary repetition is a reasonable incurred cost to ensure that all children are being properly tested. However, the results noted that roughly 1/3rd of the eligible population that should have received at least one lead test during the study period did not. This suggests that current methods to coordinate lead testing across the state population may not be adequate to ensure that at-risk children are receiving appropriate care.

LIMITATIONS

There are limitations to these study results. The cohort being studied is based upon an attribution formula that assigns patients to the ACO based upon (1) participation in a complex care coordination program in place (selection of CHC-MN to receive care) and (2) plurality of care given at a children's hospital/clinic. Given that patients can elect

where they receive a majority of their care, patients self-select to the attributed population. This may impact the generalizability of the study results.

Children's hospitals have a set of potentially distinct characteristics from general hospitals including the setting, patient demographics, the nature and severity of conditions treated and distinct protocols or pathways in place (Meurer, 1998; Merenstein, 2005). Care should be taken in applying these results across a general pediatric population.

Limitations in the secondary use of Medicaid claims data for research are cited by some as problematic when it comes to claim accuracy and the lack of clinical specificity with regards to diagnoses and underlying test results (Hsia, 1988; Seiber, 2007; Chisholm, 2009; CMS, 2013). Standard audit process for testing Medicaid claims error rates occur annually. The PERM (Payment Error Rate Measurement program) is sponsored by CMS and involves state evaluations on a rolling three-year test cycle. As of the 2010 test cycle (which includes Minnesota), the national error rate for payment was 1.89% +/- 0.62%. (range from 1-3%). State results range from 0.6 to 3.8%. Overall, Medicaid views these national results optimistically suggesting that no systemic problems exist in the results (Chisholm, 2009). Enrollment continuity, often cited as a problem in using Medicaid data, was addressed by limiting the population to those patients who were enrolled for at least 12 months (Crystal, 2007). Regarding the lack of complete information, such limitations are more a function of the nature of the study being conducted than of the underlying limitations of the data (Dumbkowski, 2012; Cooke, 2013). For purposes of this evaluation, the population-based approach to this study should mitigate the effect of any limitations in the use of Medicaid claims data on the results of the study.

In some circumstances, the criteria developed for measuring problematic tests may incorrectly identify an appropriate test as problematic. For example, a patient

receiving a repeat test within 90 days without evidence of previous elevated blood lead levels based upon ICD-9 terminology may be receiving a repeat test because a family member was identified as at risk. While rare, these situations may impact the criteria's case detection sensitivity. An exhaustive list of symptoms, conditions or diagnoses that would rule out a problematic test were included to adjust for this risk.

The statistical methods used for this study do not fully address the impact of correlated data on study results. Naturally occurring groups such as patients and health systems may have more similar observations than different groups. The lack of independence between individual study samples (in this case, test instances) may lead to differences in the standard errors that can impact study results (Hanley, 2003; Sainani, 2010). Several mitigating factors may reduce the potential effect of clustering on these study results. Mitigating factors that reduce the effect of correlated data in this study include the number of patients with two tests (10% of the study population) and the number of patients with more than two tests (less than 1% of the study population). However, further analysis is required to fully account for the impact of correlated data on study results.

Changes in the approach to care delivery resulting from the presence of the accountable care agreement could influence study results. While agreement terms are confidential, under the agreement CHC-MN is increasingly accountable for the total cost of care of this patient population during the term of the agreement. As part of conducting this study, the author performed a complete review of the agreement to assess material terms or conditions that might impact study results. No material issues were identified.

CONCLUSIONS

Lead test repetition is appropriate in providing proper screening, diagnostic and monitoring care. The results highlight the impact that fragmented preventive care,

delivered across health system with limited information sharing, can have on the cost and quality of care. Evidence from this study indicates that a portion of lead testing is problematic based upon a comparison of test sequencing and timing within established guidelines. Problematic repeat tests include tests that are repetitive or unnecessary as well as tests repeated too soon following the index test, marginalizing the test value. The results suggest that approximately 50% of repeat lead testing performed is of questionable clinical value when measured against guidelines and that access to a common information system may lower problematic testing. Prior lead test results available for patients receiving care within one health system appear to reduce the risk of problematic lead testing. Further research is needed to separately evaluate the effectiveness of a common queryable information system given the potential impact that organization policy and practice may have on test repetition. Future Medicaid accountable care agreements between the state Medicaid program and participating health systems might include clear population accountability for performing lead or other test screenings to improve patient safety and lower the cost of care.

REFERENCES

For references, see the dissertation bibliography section.

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OVERALL DISCUSSION AND CONCLUSIONS

Evaluating the benefits of health information technology is a complex undertaking. These initial studies suggest the potential for electronic health information technology to impact health care delivery for children, including the potential to reduce patient cost and improve care quality by reducing inappropriate test instances.

The underlying hypothesis for these population-based studies was that a portion of repeat test instances within a pediatric population results from a lack of clinician access to prior test results observable within an electronic health record. Clinicians with access to prior test results observable through an electronic health record will order fewer repeat tests than clinicians who do not have access to prior test results. To test this hypothesis, four specific aims were identified. First, to characterize the repeat test instances within a pediatric population and to measure the effect of health system use as a proxy for accessible prior test results on the odds of repeat test instances across all test types. Second, to measure the effect of facility type on the association between health system use and repeat test instances. Third, to define a reasonable criteria for problematic repeat lead tests. Fourth, to measure the effect of multiple health system use as a proxy for accessible prior test results on the incidence of problematic repeat lead testing.

In characterizing repeat test instances as noted in the first paper, the study results identified several risk factors associated with repeat test instances in children including age, residence, health status, health plan type and facility type. It was demonstrated that a test instance performed on patients using multiple health systems was more likely to be a repeat test instance for certain facility types than for patients having all test instances performed within the same health system where prior test results were potentially accessible. It was also demonstrated that the incidence of repeat test instances will be higher among patients who receive care across multiple

health systems than in patients who receives all patient care within a single health system.. This study contributes to our scientific understanding by characterizing several risk factors associated with repeat testing in children. Of particular importance is the identification of an association between multiple health system use and repeat testing more generally in pediatric populations. These results provide preliminary evidence suggesting that a level of repeat testing in pediatric populations may be associated with patient movement between health systems, and based upon a lack of physician access to prior test results, may be redundant.

In measuring the effect of facility type on the association between multiple health system use and repeat test instances in the second paper, it was found, consistent with studies in adults that the level of test repetition varied considerably based upon the facility type. Hospital-based care was associated with a significantly higher level of repeat testing than outpatient and primary care. This is due in large measure to differences in the intensity and underlying processes of care between facility types. Analyzing each facility type, contradictory results were found. In inpatient settings, patients using more than one health system for inpatient care had lower repeat test instances than patients using a single health system. This is due in large part to the fact that over 80% of patients using the same health system used CHC-MN. Patients who utilize CHC-MN for inpatient care are more infirm with more chronic comorbidities. Consistent with the original hypothesis, a single health system and presumably a single health record, may prove most beneficial in controlling the risk of unnecessary repeat test instances in primary care settings. Additional data regarding the risk of repeat test instances in patients transitioning between facility types was not available for this study and may prove useful in further clarifying this finding. This paper contributed to our scientific understanding by confirming, consistent with adults, that repeat testing is associated with higher care intensity, particularly in inpatient settings. The effect of

multiple health system use on increased test repetition appears more pronounced in primary care settings.

In the third paper, a common medical test was used for childhood screening and diagnosis of lead poisoning to further refine assumptions. A reasonable criteria was used for the identification of problematic repeat lead tests and characterized the nature and level of problematic repeat lead tests within the population. Approximately 50% of all repeat lead tests were problematic. Through this, it was demonstrated that the likelihood of problematic repeat testing was meaningfully lower in situations where index and repeat tests were performed within one health system, presuming that physicians had reasonable access to prior test results. While not conclusive these findings contribute strong evidence supporting the relationship between accessibility of prior test results available in an electronic health record or other queryable health information solution and physician decisions regarding the utilization of subsequent testing resources for a specific test.

OVERALL STUDY LIMITATIONS

Despite these results, barriers remain to achieving the anticipated population-based testing efficiencies associated with sharing electronic test information The fact that each health care system has a separate electronic health record system makes it difficult to separate the impact of accessible test results from an electronic health record from the effect of each health system's policies and practices on the incidence of repeat test instances. This gives rise to a possible alternative explanation for these results. Health information technology enables innovation but only to the extent that HIT availability aligns with the human decision-making needs of an organization. Evidence suggests that physicians will seek information but only if its deemed to be relevant to the decision at hand, reliable in terms of information quality, and timely (Andrews, 2005;

Coumou, 2006). For example, clinicians may have accessible test results from another health system but still elect to repeat tests as a matter of preference given concerns regarding the relevance and reliability of the test data or due to health system policy that encourages clinicians to repeat tests using only health system testing resources. The impact of hospital and clinician preferences is that some portion of the incremental test repetition identified through this study may result from these mechanisms. This makes it difficult to estimate the effective impact that making prior tests results accessible through either a single electronic health record or through the health information exchange will have on the incidence of unnecessary repeat test instances. Future study is required to separate the effect of health system policy from the impact of accessible prior test results on the level of repeat test instances.

The cohort being studied is based upon an attribution formula that assigns patients to the ACO based upon participation in a complex care coordination program in place and a plurality of care is given at a CHC-MN primary care clinic. Given that patients can elect where they receive a majority of their care, patients self-select to the attributed population. This may impact the generalizability of the study results.

Children's hospitals have a set of potentially distinct characteristics from general hospitals including the setting, patient demographics, the nature and severity of conditions treated and distinct protocols or pathways in place (Meurer, 1998; Merenstein, 2005). Care should be taken in applying these results across a general pediatric population.

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sponsored by CMS and involves state evaluations on a rolling three-year test cycle. As of the 2010 test cycle (which includes Minnesota), the national error rate for payment was 1.89% +/- 0.62%. (range from 1-3%). State results range from 0.6 to 3.8%. Overall, Medicaid views these national results optimistically suggesting that no systemic problems exist in the results (Chisholm, 2009). Enrollment continuity, often cited as a problem in using Medicaid data, was addressed by limiting the population to those patients who were enrolled for at least 12 months (Crystal, 2007). Regarding the lack of complete information, such limitations are more a function of the nature of the study being conducted than of the underlying limitations of the data (Dumbkowski, 2012; Cooke, 2013). For purposes of this evaluation, the population-based approach to this study should limit the effect of limitations in the use of Medicaid claims data on the results of the study.

The statistical methods used for this study do not fully address the impact of correlated data on study results. Naturally occurring groups such as patients and health systems may have more similar observations than different groups. The lack of independence between individual study samples (in this case, test instances) may lead to differences in the standard errors that can impact study results (Hanley, 2003; Sainani, 2010). Several mitigating factors may reduce the potential effect of clustering on these study results. The primary explanatory variable (patients who use one health system versus patients using more than one health system) was already partially aggregated to weight for the effect of patient clustering. Results also demonstrated that the study effect remained after removing patients with more than 25 transactions where the impact of correlated data would be more pronounced. However, further analysis is required to fully account for the impact of correlated data on study results.

Changes in the approach to care delivery resulting from the presence of the accountable care agreement could influence study results. While agreement terms are

confidential, under the agreement CHC-MN is increasingly accountable for the total cost of care of this patient population during the term of the agreement. As part of conducting this study, the author performed a complete review of the agreement to assess material terms or conditions that might impact study results. No material issues were identified.

CONTRIBUTION AND FUTURE DIRECTIONS

These studies make significant contributions to health informatics and to health services research in several important ways. Publications associated with this research will be submitted to the Journal of Population Health Management for consideration as well as to other relevant journals.

Population-based studies are increasingly important given changes in healthcare financing under the Affordable Care Act. The use of population claims data with complete patient activity across all providers offered a novel glimpse into a specific context - the interaction of pediatric care providers with a children's hospital system within a large metropolitan area. Such contextual studies will become increasingly common to measure both patient health and patient use of the healthcare resources. Studies focused on identifying other forms of repetition within these populations that result from a lack of access to prior healthcare-related information may prove insightful in efforts to eliminate redundant care. Such research may also prove interesting in measuring other forms of repetition not captured today, such as readmissions, that result as patients within a population move between health systems. In many cases, these analytic methods are scalable to increasingly larger populations of patients.

These studies represent a first effort to characterize the incidence of repeat test instances in a pediatric population along with risk factors, including patient use of multiple health systems.. Testing usage patterns differ between adult and pediatric populations making separate research into pediatric population-based management of

medical testing necessary, particularly if such efforts are aligned with quality and utilization target setting programs. Understanding risk factors for medical test repetition aids in subsequent efforts to identify the root causes of inappropriate testing in children in an effort to eliminate waste.

These studies introduced useful methods for measuring repetition using claims data, particularly in situations where clinical test results were not available. Such methods are important in framing population-based management strategies to identify and reduce the incidence of inappropriate testing in pediatric populations. Of particular note was the use of hierarchical data modeling methods for the identification of repetition in a population. In addition, the approach taken to develop useful clinical criteria to identify problematic repeat tests can be applied as well with other tests.

Finally, these studies have important implications for state and national efforts to promote greater information sharing across physicians and health systems as a mechanism for reducing unnecessary healthcare expenditures. At the federal level, stage 3 meaningful use criteria is currently in development with a focus on the use of EHR technology to improve quality outcomes and population health (HHS-ONCHIT, 2104). Consistent with national goals, in the State of Minnesota, statutes require interoperability of electronic health records by 2015 (MN Statute 62J.495). Evidence quantifying the impact of prior clinical information on utilization and cost can inform these efforts relative to pediatric settings. Meaningful use of health information exchange across pediatric populations shows promise in improving care quality and lowering per patient cost of care. Further research is needed to examine the impact prior clinical information in the form of an accessible electronic health record can have on other common tests and imaging procedures.

BIBLIOGRAPHY

Advisory Committee for Childhood Lead Poisoning (ACCLP) of the Centers for Disease Control and Prevention. Guidelines for Measuring Lead in Blood Using Point of Care Instruments. 2013 [cited 21 May 2014]. Available at. http://www.cdc.gov/nceh/lead/ACCLPP/20131024_POCguidelines_final.pdf.

Aetna. Clinical Policy Bulletin: Lead Testing. 2014 [cited 22 May 2014]. Available from http://www.aetna.com/cpb/medical/data/500_599/0553.html

Affolter N, Krahenbuhl S, Schlienger RG. Appropriateness of serum level determinations of antiepileptic drugs. Swiss Med Wkly 2003;133:591-7.

Agency for Healthcare Research and Quality (AHRQ), US Department of Health an Human Services. Prevention and Chronic Care Program. 2012 [cited 10 May 2012) Available from http://www.ahrq.gov/clinic/pcc/decsupport.htm.

Alexander B. Reducing healthcare costs through appropriate test utilization. Critical Values 2012; 5(2): 6–8.

American Medical Association: American Board of Internal Medicine Foundation (ABIMF): Care Transitions Performance Measurement Set (Phase I: Inpatient discharges and emergency patient discharges). Chicago, IL: American Medical Association, 2009.

Andrews JE, Pearce KA, Ireson C, Love MM. Information-seeking behaviors of practitioners in a primary care practice-based resarch network. J Med Libr Assoc. 2005;93(2):6

Appari A, Carian EK, Johnson ME, Anthony DL. Medication administration quality and health information technology: a national study of US hospitals. J. Am. Med. Inform. Assoc 2012;19(3):360–7.

Auger K, Kenyon CC, Feudtner C, Davis MM. Pediatric hospital discharge interventions to reduce subsequent utilization: A systematic review. J Hosp Med. 2013 12(20):1–10.

Bassi J, Lau F. Measuring value for money: a scoping review on economic evaluation of health information technology. J. Am. Med. Inform. Assoc. 2013; 20(4):792–801.

Bates DW, Leape LL, Cullen DJ, Laird N, Petersen LA, Teich JM, et al. Effect of computerized physician order entry and a team intervention on prevention of serious medication errors. JAMA. 1998; 280(15):1311–6.

Bates DW, Boyle DL, Rittenberg E, Huperman GJ, Ma'Luf N, Menkin V, et.al, What Proportion of Common Diagnostic Tests Appear Redundant? AM J Med 1998; 104(4): 361-8.

Bates DW, Kuperman GJ, Ritternebrg E, Teich JM, Fiskio J, Ma'Luf N, and et.al. A randomized trial of a computer intervention to reduce redundant laboratory tests. Am J Med 1999; 106(2) 144-50.

Berwick DM, Nolan TW, Whittington J. "The Triple Aim: care, health and cost," Health Affairs. 2008; 27(3) 759-769.

Bindman AB, Chattopadhyay A, Osmond DH, Huen W, Bacchetti P. Medicaid The Impact of Medicaid Managed Care on Hospitalizations for Ambulatory Care Sensitive Conditions. 1999;19–39.

Black AD, Car J, Pagliari C, Anandan C, Cresswell K, Bokun T, et al. The impact of eHealth on the quality and safety of health care: a systematic overview. PLoS Med. 2011 Jan; 8(1):e1000387.

Bloomberg Visual Data: Most efficient health care: Countries. New York: Bloomberg; 2013 [cited 11 February 2014]. Available from: http://www.bloomberg.com/visual-data/best-and-worst/most-efficient-health-care-countries.

Branger PJ, Van Oers RJ, van der Wouden JC, van der Lei J. Laboratory services utilization: a survey of repeat investigations in ambulatory care. Neth J Med 1995; 47: 208-213.

Bugter-MaessenAM,Winkens RA, Grol RP, et al. Factors predicting differences among general practitioners in test ordering behavior and in the response to feedback on test requests. Fam Pract. 1996;13:254-258.

Buntin MB, Burke MF, Hoaglin MC, Blumenthal D. The benefits of health information technology: a review of the recent literature shows predominantly positive results. Health Aff. (Millwood). 2011; 30(3):464–71.

Canas F, Tanasijevic MJ, Ma'luf N, Bates DW. Evaluating the appropriateness of digoxin level monitoring. Arch Intern Med 1999;159:363-8.

Chaudhry B, Wang J, Shekelle P, et.al. Annals of Internal Medicine Improving Patient Care Systematic Review: Impact of Health Information Technology on Quality, Efficiency and Costs of Medical Care. Annals of Internal Medicine. 2006; 144:742-52.Chisolm DJ,

Chisolm DJ, Scribano P V, Purnell TS, Kelleher KJ. Development of a computerized medical history profile for children in out-of-home placement using Medicaid data. J Health Care Poor Underserved. 2009 20(3): 748–55.

Connelly DP, Park Y-T, Du J, Theera-Ampornpunt N, Gordon BD, Bershow B a, et al. The impact of electronic health records on care of heart failure patients in the emergency room. Journal of the American Medical Informatics Association : JAMIA [Internet]. 2011 Nov 9 [cited 2012 Mar 7]

Cooke CR, Iwashyna TJ. Using existing data to address important clinical questions in critical care. Crit Care Med. 2013]; 41(3):886–96.

Coumou CH, Meijman FJ. How do primary care physicians seeks answers to clinical questions? A literature review. J Med Libr Assoc. 2006;94(1):5.

Crystal S, Akincigil A, Bilder S, et al. Studying prescription drug use and outcomes with Medicaid claims data. Med Care. 2007;10:S58 –S65.

DesRoches CM, Campbell EG, Vogeli C, Zheng J, Rao SR, Shields AE, et al. Electronic health records' limited successes suggest more targeted uses. Health affairs (Project Hope). 2010; 29(4):639–46.

Dombkowski KJ, Lamarand K, Dong S, Perng W, Clark SJ. Using Medicaid Claims to Identify Children With Asthma. 2012; 48109(3): 196–203.

Dorevitch AP (1992) The ''Ulysses syndrome'' in pathology: when more is less. Med J Aust 156: 140.

Dowding DW, Turley M, Garrido T. The impact of an electronic health record on nurse sensitive patient outcomes: an interrupted time series analysis. J. Am. Med. Inform. Assoc. 2012;19(4):615–20.

Du J, Park YT, Theera-Ampornpunt N, McCullough Jeffrey, Speedie SM. The use of count data models in biomedical informatics research. JAMIA 2012. 19: (1): 39-44.

Epstein AM, McNeil BJ. Relationship of beliefs and behavior in test ordering. Am J Med. 1986;80: 865-870.

Eva F, Rosanna Q, Laura C, Piero C, Silvio B. Appropriate laboratory utilization in diagnosing pulmonary embolism. Ann Clin Biochem 2009;46:18-23.

Fergeson MA, Mulvihill JJ, Schaefer GB, Dehaai KA, Piatt J, Combs K, et al. Low adherence to national guidelines for thyroid screening in down syndrome. Genet Med 2009;11:548-51.

Fuchs, VR. The gross domestic product and healthcare spending. NEJM 2013; 269: 108-109.

Furukawa MF. Electronic medical records and the efficiency of hospital emergency departments. Med. Care Res. Rev. [Internet]. 2011; 68(1):75–95.

Furukawa MF, Raghu TS, Shao BBM. Electronic medical records, nurse staffing, and nurse-sensitive patient outcomes: evidence from California hospitals, 1998-2007. Health Serv. Res. 2010;45(4):941–62.

Gallego AI, Gagnon M-P, Desmartis M. Assessing the cost of electronic health records: a review of cost indicators. Telemed. J. E. Health. 2010;16(9):963–72.

Gold J. Accountable Care Organizations, Explained. Kaiser Health News, NPR. Jan 18, 2011. http://www.npr.org/2011/04/01/132937232/accountable-care-organizations-explained

Gosden T, Forland F, Kristiansen IS. "Capitation, salary, fee-for-service and mixed systems of payment: effects on the behaviour of primary care physicians". *Cochrane Database Syst Rev*. 2000; (3): CD002215.

Griffith CH III, Wilson JF, Desai NS, Rich EC. Does pediatric housestaff experience influence tests ordered for infants in the neonatal intensive care unit? Crit Care Med. 1997;25:704-709.

Gupta R, Greer SE, Martin ED. Inefficiencies in a rural trauma system: the burden of repeat imaging in interfacility transfers. J Trauma 2010;69(2):253–5. [7]

Hanley JA, Negessa A, Edwardes MD, Forrester JE. Statistical analysis of correlated data using generalized estimating equations: an orientation. Am J Epidemiol 2003; 157: 364-375.

Hanna DB, Tsoi BW, Begier EM. Most positive hiv western blot tests do not diagnose new cases in new york city: Implications for hiv testing programs. J Acquir Immune Defic Syndr 2009;51:609-14.

Häyrinen K, Saranto K, Nykänen P. Definition, structure, content, use and impacts of electronic health records: a review of the research literature. International journal of medical informatics. 2008; 77(5):291–304

Hillestad R, Bigelow J, Bower A, Girosi F, Meili R, Scoville R, et al. Can electronic medical record systems transform health care? Potential health benefits, savings, and costs. Health affairs (Project Hope). 2005; 24(5):1103–17.

Himmelstein DU, Wright A, Woolhandler S. Hospital computing and the costs and quality of care: a national study. The American journal of medicine. 2010; 123(1):40-46.

Hsia DC, Krushat WM, Fagan AB, et al. Accuracy of diagnostic coding for Medicare patients under the prospective-payment system. N Engl J Med. 1988;318:352–355

Huissoon AP, Carlton SA. Unnecessary repeat requesting of tests in a university teaching hospital immunology laboratory: An audit. J Clin Pathol 2002;55:78.

Jha AK, DesRoches CM, Campbell EG, Donelan K, Rao SR, Ferris TG, et al. Use of electronic health records in U.S. hospitals. NEJM. 2009; 360(16):1628–38.

The Johns Hopkins Bloomberg School of Public Health. The Johns Hopkins ACG System. Excerpt from technical reference guide, June 2009. Version 2.0. Accessed September 20, 2014 at https://www.healthpartners.com/files/ 57460.pdf.

Jones S, Friedberg M, Schneider E. Health information exchange, health information technology use and hospital readmission rates. AMIA Annu. Proceeding. 2011. p. 644–53.

Katz EB, Carrier ER, Umscheid C a, Pines JM. Comparative effectiveness of care coordination interventions in the emergency department: a systematic review. Ann Emerg Med. 2012: 60(1):12–23

Kerfoot BP, Holmberg EF, Lawler EV, Krupat E, Conlin PR. Practitioner-level determinants of inappropriate prostate-specific antigen screening. Arch Intern Med 2007;167:1367-72.

Knighton AJ, Payne NR, Speedie SM. Deriving value from health information technology: impact of prior clinical information from an accessible electronic health record on laboratory and radiology testing in a pediatric population [dissertation]. [Minneapolis (MN)]: University of Minnesota; 2015. 98 p.

Kwok J, Jones B. Unnecessary repeat requesting of tests: An audit in a government hospital immunology laboratory. J Clin Pathol 2005;58:457-62.

Laxmisan A, Vaughan-Sarrazin M, Cram P. Repeated hemoglobin a1c ordering in the va health system. Am J Med 2011;124:342-9.

Leaver H, Keng Lim T, Thomson P, Leaver J, Choy AM, Lang CC. Compliance to recommended liver function monitoring in patients on statin therapy. Cardiovasc Ther 2009;27:96-100.

Lee JA, Zierler BK. The current state of practice in the diagnosis of venous thromboembolism at an academic medical center. Vasc Endovascular Surg 2011;45:22-7.

Lee J, Kuo Y-F, Goodwin JS. The effect of electronic medical record adoption on outcomes in US hospitals. BMC Health Serv. Res. BMC Health Services Research; 2013;13(1): 39.

Linder J a, Ma J, Bates DW, Middleton B, Stafford RS. Electronic health record use and the quality of ambulatory care in the United States. Archives of internal medicine. 2007 Jul 9; 167(13):1400–5

Maslove DM, Rizk N, Lowe HJ. Computerized physician order entry in the critical care environment: a review of current literature. J Intensive Care Med. 2011(3): 165–71.

McGillivrayDL,Roberts-BrauerR,KramerMS. Diagnostic test ordering in the evaluation of febrile children: physician and environmental factors. AJDC. 1993;147:870-874.

Mello MM, Chandra A, Gawande AA, Studdert DM (2010) National costs of the medical liability system. Health Aff (Millwood) 29: 1569–1577

Menachemi N, Collum TH. Benefits and drawbacks of electronic health record systems. Risk Manag. Healthc. Policy. 2011; 4:47–55.

Mepham SO, Squire SB, Chisuwo L, Kandulu J, Bates I. Utilisation of laboratory services by health workers in a district hospital in malawi. J Clin Pathol 2009;62:935-8.

Merenstein D, Egleston B, Diener-West M. Lengths of stay an costs associated with children's hospitals. Pediatrics 2005;115:839–844.

Merlani P, Garnerin P, Diby M, Ferring M, Ricou B. Quality improvement report: Linking guideline to regular feedback to increase appropriate requests for clinical tests: Blood gas analysis in intensive care. BMJ 2001;323:620-4.

Meurer JR, Kuhn EM, George V, Yauck JS, Layde PM. Charges for childhood asthma by hospital characteristics. Pediatrics 1998;102:1471–1472.

Minnesota Department of Health. Minnesota e-Health Report. Hospitals: Adoption and Use of Electronic Health Records and Exchange of Health Information. March 2013.

Minnesota Department of Health. Minnesota e-Health Report. Clinics: Adoption and Use of EHRs and Exchange of Health Information, 2013. August 2013.

Minnesota Department of Health. Lead poisoning and prevention website accessed September 21, 2014 at http://www.health.state.mn.us/divs/eh/lead/.

Minnesota Department of Human Services web site. Accessed June 9, 2014 at http://mn.gov/dhs/.

Mordasini MR, Krahenbuhl S, Schlienger RG. Appropriateness of digoxin level monitoring. Swiss Med Wkly 2002;132:506-12.

Miyakis S, Karamanof G, Liontos M, Mountokalakis TD. Factors contributing to inappropriate ordering of tests in an academic medical department and the effect of an educational feedback strategy. Postgrad Med J 2006;82:823-9.

National Quality Forum (NWF). National Priorities Partnership: Input to the Secretary of Health and Human Services on Priority for the National Quality Strategy, Washington, DC: National Quality Forum, 2011.

Niazkhani Z, Pirnejad H, Berg M, Aarts J. The impact of computerized provider order entry systems on inpatient clinical workflow: a literature review. J Am Med Inform Assoc. 2009;16(4): 539–49.

Ozbek OA, Oktem MA, Dogan G, Abacioglu YH. Application of hepatitis serology testing algorithms to assess inappropriate laboratory utilization. J Eval Clin Pract 2004;10:519-23.

Phillips RLP, Han M, Petterson SM, Makaroff L, Liaw WR. Cost, Utilization, and Quality of Care: An Evaluation of Illinois' Medicaid Primary Care Case Management Program. 2014;408–17.

Poon EG, Wright A, Simon SR, Jenter CA, Kaushal R, Volk LA, Cleary PD, Singer JA, Tumolo AZ, Bates DW. Relationship between use of electronic health record features and health care quality: results of a statewide survey. Med Care. 2010; 48(3):203-9.

Poteat HT, Chen P, Loughlin KR, Winkelman JW, Allada R, Ma'luf N, et al. Appropriateness of prostate-specific antigen testing. Am J Clin Pathol 2000;113:421-8.

Rang, M. The Ulysses Syndrome. CMAJ. 1972; 106:122-123.

Rehmani R, Amanullah S. Analysis of blood tests in the emergency department of a tertiary care hospital. Postgrad Med J 1999;75:662-6.

Sainani, K. The importance of accounting for correlated observations. American Academiy of Physician Medicine and Rehabilitation 2010; 2: 858-861.

Schoen C, Osborne R. The Commonwealth Fund 2011 International Health Policy Surey of Sicker Adults in Eleven Countries. Commonwealth Fund. Accessed September 20, 2014 at www.commonwealthfund.org/Publications.

Scribano P V, Purnell TS, Kelleher KJ. Development of a computerized medical history profile for children in out-of-home placement using Medicaid data. J Health Care Poor Underserved. 2009 Aug; 20(3): 748–55.

Seferian EG, Carson SS, Pohlman A, Hall J. Comparison of resource utilization and outcome between pediatric and adult intensive care unit patients. Pediatr Crit Care Med. 2001; 2(1): 2–8.

Seiber EE. Physician code creep: evidence in Medicaid and state employee health insurance billing. Health Care Finance Rev. 2007;28:83–93.

Shekelle PG, Morton SC, Keeler EB. Costs and Benefits of Health Information Technology. Evidence Report/Technology Assessment No. 132. (Prepared by the Southern California Evidence-based Practice Center under Contract No. 290-02-0003.) AHRQ Publication No. Rockville, MD: Agency for Healthcare Research and Quality. April 2006.

Stair TO. Reduction of redundant laboratory orders by access to computerized patient records. J Emerg Med 1998;16(6):895–7

Starfield B, Kinder K. Multimorbidity and its measurement. Health Policy. 2011; 103(1): 3–8.

Sunshine RA. Letter to Honorable Charles Rangel, Chairman, Committee on Ways and Means, US House of Representatives. Washington D.C: Congressional Budget Office, January 21, 2009.

Teufel RJ, Kazley AS, Basco WT. Is computerized physician order entry use associated with a decrease in hospital resource utilization in hospitals that care for children? J. Med. Syst. 2012; 36(4): 2411–20.

Teufel RJ, Kazley AS, Ebeling MD, Basco WT. Hospital electronic medical record use and cost of inpatient pediatric care. Acad. Pediatr. 2012; 12(5):429–35.

Thomas SH, Orf J, Peterson C, Wedel SK. Frequency and costs of laboratory and radiograph repetition in trauma patients undergoing interfacility transfer. Am J Emerg Med 2000;18(2):156–8.

US Department of Health and Human Services, Centers for Disease Control and Prevention. Response to Advisory Committee on Childhood Lead Poisoning Prevention Recommendations [Internet]. Atlanta(GA): 2012 [cited 2014 May 21]. Available from: http://www.cdc.gov/nceh/lead/acclpp/cdc_response_lead_exposure_recs.pdf

US Department of Health and Human Services. Centers For Disease Control and Prevention. Managing Elevated Blood Lead Levels Among Young Children: Recommendations from the Advisory Committee on Childhood Lead Poisoning Prevention: Case Management Guidelines [Internet]. Atlanta (GA): 2014a. [cited 2014 May 22] from http://www.cdc.gov/nceh/lead/casemanagement/caseManage_chap3.htm

US Department of Health and Human Servics. Centers for Disease Control and Prevention. Lead. Blood Lead Levels [Internet]. Atlanta(GA): 2014b [cited 2014 September 21]. Available from: http://www.cdc.gov/nceh/lead/acclpp/blood_lead_levels.html

US Department of Health and Human Services. Centers for Disease Control and Prevention. Lead. National Statistics [Internet]. Atlanta(GA):2014c [cited 2014 September 21]. Available from: http://www.cdc.gov/nceh/lead/data/national.htm

US Department of Health and Human Services. Centers for Medicare and Medicaid Services. Electronic Health Records at a Glance - EHR Incentive programs. Baltimore (MD): 2010 [cited 2012 Mar 30]. Available from: http://www.cms.gov/Regulations-and-Guidance/Legislation/EHRIncentivePrograms/index.html?redirect=/ehrincentiveprograms/30_Meaningful_Use.asp

US Department of Health and Human Services, Center for Medicare and Medicaid Services. What Providers Need to Know: Accountable Care [Internet]. 2011a [cited 2014 Sep 30]. Available from: http://www.cms.gov/Medicare/Medicare-Fee-for-Service-Payment/sharedsavingsprogram/Downloads/ACO_Providers_Factsheet_ICN907406.pdf

US Department of Health and Human Services, Centers for Medicare & Medicaid Services. Medicare Shared Savings Program: Accountable Care Organizations; Proposed rules. Fed Regist. 2011b Apr 7;76(67): 19528-19600.

US Department of Health and Human Services. Centers for Medicare and Medicaid Services. Medicaid Improper Payment Report – FY 2010. Baltimore(MD): 2013 [cited 2013 Oct 26]. Available from: http://www.cms.gov/Research-Statistics- Data-and-Systems/Monitoring Programs/PERM/Reports_and_Reference_Documents.html accessed on Dec 19, 2013.

US Department of Health and Human Services. Centers for Medicare and Medicaid Services. Medicaid. Baltimore (MD): 2014a [cited 2014 May 1]. Available from: http://www.medicaid.gov/Medicaid-CHIP-Program-Information/By-Topics/Benefits/Early-and-Periodic-Screening-Diagnostic-and-Treatment.html

US Department of Health and Human Services. Centers for Medicare and Medicaid Services. Medicare Provider Analysis and Review (MEDPAR) File. Baltimore(MD): 2014b [cited 2014 Nov 1]. Available from: http://www.cms.gov/Research-Statistics-Data-and-Systems/Files-for-Order/IdentifiableDataFiles/MedicareProviderAnalysisandReviewFile.html

US Department of Health and Human Services, Office of the National Coordinator for Health Information Technology. Reference Grids for Meaningful Use or Standards and Certification Criteria Final Rules. Washington (DC): 2012 [cited 2012 Mar 30]. Available from: www.hhs.gov.

US Department of Health and Human Services, Office of the National Coordinator on Health Information Technology (ONCHIT). How to attain meaningful use. Washington(DC): 2014 [cited 2014 December 6]. Available from: http://www.healthit.gov/providers-professionals/how-attain-meaningful-use.

Valenstein P, Leiken A, Lehmann C. Test-ordering by multiple physicians increases unnecessary laboratory examinations. Arch Pathol Lab Med 1988;112:238–41. 18.

Van Walraven C, Naylor CD. Do we know what inappropriate laboratory utilization is? A systematic review of laboratory clinical audits. JAMA 1998; 280 (6): 550–8.

Van Walraven C, Raymond M. Population-based study of repeat laboratory testing. Clin Chem. 2003; 49 (12): 1997–2005.

Van Walraven, C, Cernat G, Austin PC. Effect of Provider Continuuity on test repetition. Clin Chemistry 2006: Dec; 52(12) 2219-2228.

Walters RJ, Hutchings AD, Smith DF, Smith PE. Inappropriate requests for serum anti-epileptic drug levels in hospital practice. QJM 2004;97:337-41.

Wengrovitz, A, Brown MJ. US Department of Health and Human Services, Centers for Disease Control and Prevention. MMWR recommendations and reports [Internet]. Atlanga (GA): 2009 [cited 2014 May 21]. Available from http://www.cdc.gov/mmwr/preview/mmwrhtml/rr5809a1.htm

Were MC, Shen C, Tierney WM, Mamlin JJ, Biondich PG, Li X, et al. Evaluation of computer-generated reminders to improve cd4 laboratory monitoring in sub-saharan africa: A prospective comparative study. J Am Med Inform Assoc 2011;18:150-5.

Williams SV, Eisenberg JM, Pascale LA, Kitz DS. Physicians' perceptions about unnecessary diagnostic testing. Inquiry. 1982;19:363-370.

Zhi M, Ding EL, Theisen-Toupal J, et al.. The landscape of inappropriate laboratory testing: A 15-year meta-analysis. PLoS One 2013; 8 (11): 1-8.

Zlabek J a, Wickus JW, Mathiason M a. Early cost and safety benefits of an inpatient electronic health record. J. Am. Med. Inform. Assoc. [Internet]. 2009 [cited 2013 Sep 19];18(2):169–72.