A Decade of Health Information Technology and the Impact on Health Care in the U.S.: Systematic Review

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Abstract

Background: In 2004, the Office of the National Coordinator for Health Information Technology (ONC) was established to facilitate the nationwide adoption and use of health information technology (health IT). Since its inception, the health IT landscape has evolved with a diverse array of federal investments, programs, and policies to advance its use. Previous systematic reviews of literature related to health IT focused on assessing the adoption and use of technology. As health IT has evolved, research has pivoted from tracking adoption of specific health IT features to assessing the impact of these technologies and tools.

Objective: This paper provides a comprehensive review of peer-reviewed publications published over the past decade to closely examine the impacts of health IT including the impact of federal policies, changing priorities, and how the expanded use of EHR features, and effect of health IT on people, processes, and outcomes.

Methods: All health IT-related peer-reviewed published between January 2013 and June 2023 were evaluated to identify articles that focused on the impact of health IT. Articles and studies were extracted through a review of PubMed. A stepwise process was used to identify articles that met the inclusion criteria, focused on the impact of health IT, and demonstrated sufficient scientific rigor.

Results: The resulting 408 articles were coded based on their primary focus (provider-facing or patient-facing technology), or based on topics that pertained to the systemwide use of health IT. Within each of these categories, articles were organized around key themes. Overwhelmingly, research studies reported that health IT generated a positive impact. More than half of all articles focused on provider-facing technology with a focus on measurable outcomes including quality, safety, and costs. A number of studies evaluated the increased use of patient portals and other tools to support engagement. Studies on interoperability highlighted the value of increased health information exchange. An emerging area of study included a focus on the role of health IT in advancing public and population health.

Over three-quarters of the published literature concluded that health IT generated a positive, mixed, or neutral impact. These effects were consistent across the different categories of health IT that were examined whether provider-facing, patient-facing, or systemwide impact of health IT.

Conclusions: Over the past decade, the focus of studies on the impact of health IT has evolved, transitioning from a concentration on health IT adoption to optimizing its potential. This includes assessing the effectiveness of EHR functions as well as increasing information exchange. As the landscape evolved with broader acceptance of health IT, the focus shifted with

greater interest in technology's impact on patient engagement, and opportunities to use data to advance health care including population and public health. Clinical Trial: N/A

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ABSTRACT

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Discussion

Over three-quarters of the published literature concluded that health IT generated a positive, mixed, or neutral impact. These effects were consistent across the different categories of health IT that were examined whether provider-facing, patient-facing, or systemwide impact of health IT.

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Over the past decade, the focus of studies on the impact of health IT has evolved, transitioning from a concentration on health IT adoption to optimizing its potential. This includes assessing the effectiveness of EHR functions as well as increasing information exchange. As the landscape evolved with broader acceptance of health IT, the focus shifted with greater interest in technology's impact on patient engagement, and opportunities to use data to advance health care including population and public health.

INTRODUCTION

Background

The health information technology (health IT) landscape has substantially evolved over the past twenty years. While not a new concept at the turn of the century, beginning in 2004, the federal government recognized the importance of health IT by establishing the Office of the National Coordinator for Health Information Technology (ONC) to coordinate and facilitate the nationwide adoption and use of health IT. The first Federal Health IT Strategic Plan, released in 2005 by ONC,[1] identified four primary goals to advance health IT: (1) Increase adoption and appropriate use of EHRs to inform clinical practice; (2) Establish an interoperable infrastructure to connect clinicians; (3) Advance the use of patient-facing technology to personalize care; and (4) Streamline electronic data collection to improve population health. Three years later, ONC published its 2008 Performance Plan which related progress to date and outlined a trajectory for achieving the goals outlined in the strategic plan.[2]

Over the next five years, several federal policies and programs were established to support these goals, including, but not limited to, the passage of the Health Information Technology for Economic and Clinical Health Act of 2009 (HITECH Act), the establishment of the ONC Health IT Certification Program, and the funding of Regional Extension Centers to provide direct technical assistance to health care providers.[3] Over time, the federal government has continued to advance health IT through multiple programs including incorporating health IT into Medicare payment programs, implementing provisions from the 21st Century Cures Act of 2016 to advance interoperability and

prevent information blocking, and establishing guardrails to protect patient privacy while ensuring the secure exchange of information. The evolution of health IT includes not only provider adoption, use, and exchange of health information, but the proliferation of tools to increase patient access to their health information.

Prior Research

Over the past two decades, researchers have conducted multiple literature reviews to synthesize research on health IT. A systematic review of publications between 1995 and 2003 identified approximately 800 relevant articles over the eight-year period. The identified studies primarily focused on the impact of electronic health records (EHRs), with preliminary evidence that EHR use can increase quality and efficiency. However, the studies largely focused on EHR use by four large health systems, hindering the ability to generalize the findings.[4] In 2009, a systematic review revealed a growing interest in patient-focused applications. Many of these articles were descriptive, providing a better understanding of commercial EHR products, but included limited information on their impact on health outcomes. [5]

In 2011, a team of researchers reevaluated the peer-reviewed literature, identifying increased research related to health IT, including, but not limited to, EHRs, interoperability, and health information exchange (HIEs). Peer-reviewed studies concluded that EHR adoption rapidly increased with broader adoption by different providers, including small practices.[6] Overall, the research focused on the impact of EHR adoption and use, including the electronic exchange of health information, incentivizing providers to use EHRs to perform key functions, and establishing a sustainable workforce to reinforce health IT adoption and growth. [7] In 2014, a systematic review documented evidence of the impact of the programs and policies initiated through the HITECH Act,

including incentive payments for the adoption and use of EHRs. [8] This systemic review analyzed studies published between 2010 and 2013, focusing on the specific EHR functions incorporated into the Medicare and Medicaid EHR Incentive Programs (EHR Incentive Programs) to encourage eligible health care providers and hospitals to adopt, implement, upgrade, and demonstrate meaningful use of certified EHR technology.[9] Overall, the research demonstrated the positive impact of adopting and using specific EHR features on quality; however, studies also identified challenges associated with EHR implementation and their impact on patient safety.

Objective

Since these seminal publications, the use of health IT and the volume of studies evaluating its impact have grown exponentially. Recognizing the tremendous changes realized in the first decade since the establishment of ONC, it is important to re-examine progress and changes in the focus of health IT over the subsequent decade (2013-2023). Peer-reviewed publications offer both a high-level and detailed understanding of these changes, including the impact of federal policies, shifts in the marketplace, expanded use of EHR features, and evaluations of health IT on people, processes, and outcomes. This paper expands upon prior systematic literature reviews of health IT, focusing on how health IT has evolved in parallel with federal programs, policies, and priorities.[4-7] Like previous work, this paper also assesses the effect of health IT by reviewing the overall sentiment related to the topic of interest (positive or negative effect of health IT) as well as changes in use and measurable impacts.

METHODS

Search Terms

A review of all peer-reviewed literature published between January 2013 and June 2023 was

performed using PubMed and Google Scholar. Search terms were developed through an iterative process to ensure the inclusion of a comprehensive set of topics about EHR and health IT adoption and use; the electronic exchange of health information; the health IT marketplace; health IT-enabled patient and consumer engagement; and health IT-related legal and policy issues, including privacy, security, accreditation, and data standards. The search focused on studies that described the impact of health IT on quality (e.g., clinical decision support, patient safety), access, costs, competition and marketplace, clinical and health services research and analytics, and how related federal policies over the past decade, such as the 21st Century Cures Act, aligned with ONC's mission and goals.

Inclusion/Exclusion Criteria

Search terms were selected to align with key ONC programs and objectives as well as the search terms employed in previous reviews. [6] A complete list of the search terms is included in Appendix A. Searches employed various combinations of terms to maximize the volume of retrieved articles and ensure that all relevant publications were identified. Search terms were developed through an iterative process to ensure the inclusion of a comprehensive set of topics related to health IT. Table 1 provides an overview of the topics and key terms within each area of focus.

Table 1. Literature review search terms by topic area

High-Level Topic	Search Terms
Health Information Technology	Health information technology, health IT, HIT, information technology, informatics, health infrastructure, ehealth, digital health, Electronic Medical Record, EMR, Electronic Health Record, EHR, electronic patient record, computerized medical records, health data, computerized physician order entry, CPOE, electronic medication administration, electronic prescription, e-prescribing, electronic notes, health innovation, accreditation (with EHR or health IT), Adopt (with EHR or health IT)
Information Exchange	Information sharing, interoperability, information exchange, HIE, health information utility, bi-directional data, real time information,

	data governance, Fast Healthcare Interoperability Resources, FHIR, HL7, data standards, Health information certification, Trusted Exchange Framework and Common Agreement, TEFCA
Marketplace	Open market, technology vendors, price transparency (with health information technology OR Electronic health record)
Patient-facing	Patient portal, usability, open notes, patient-centered, patient-engagement, application programming interface, API
Privacy	Protected health information, authentication
Quality	Decision support, quality measures, eCQMs, rapid reporting, automated tools, quality indicators, health equity, coordination of care, adverse effects
Costs	Cost, economics
Research	Meta analysis, predictive modeling, machine learning, data mining, impact, effect, health analytics
Policy	HITECH, 21st Century Cures Act, CARES Act, Health policy, public health, meaningful use
Other (pair with above)	Care transition, provider burden, data, population health planning, administrative simplification

Exclusion criteria were identified in collaboration with two senior staff from ONC. Articles published before 2013 and those employing non-U.S. data were excluded from the analysis. Exclusions also included studies based on qualitative data, clinical trials, pilot studies, and opinion pieces. This decision was guided by the desire to focus on research that demonstrated impact within a broader context rather than the results of a narrow research study that may not be representative of a wider set of systems, programs, or providers. This review focuses on studies examining health IT adoption and use, and the access, exchange, and use of electronic health information. Articles that focused exclusively on mobile health and blockchain were excluded given their broader scope. Research studies of telehealth were excluded as telehealth encompasses telecommunication technologies to support long-distance clinical health care, patient and professional health-related education, and health administration. Studies on conditions affecting less than 5% of the U.S. population or focused solely on dental health or long-term care settings were excluded. The review included studies across all settings and types of patients and providers. Research that did not clearly focus on health

IT's impact or articles not meeting criteria underwent team review for consensus, with regular consultations with ONC senior officials to guide final selection.

Review Process

A stepwise process was followed to identify and screen articles. From March to July 2023, the study lead, supported by four graduate-level research assistants, reviewed PubMed using various combinations of the search terms in Figure 1. The searches were conducted by year; each year was assigned to a single member of the research team (four research assistants, study lead, and co-lead). As such, some members of the research team reviewed articles over a two- or three-year span while others reviewed a single year.

All research studies identified within a given year were reassigned to different researcher on the team (other than the individual who did the original article abstraction) for a more detailed review. This ensured that the individual leading the initial data extraction process was assigned a different year in this subsequent round of review which included a careful look at the abstract. For articles where there was no abstract or the abstract did not provide sufficient information, the reviewer looked at the complete article to ensure that it met the inclusion criteria. Articles determined to be outside of the scope, duplicative, or published prior to 2013 were excluded.

Evaluation of Scientific Evidence

The remaining articles were subsequently evaluated for scientific merit by the study lead and four graduate-level research assistants. The team reviewed an array of tested methods for evaluating articles for inclusion. This included the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA), [10] the Cochrane Handbook for Systematic Reviews (Cochrane), [11] the Grading of

Recommendations, Assessment, Development and Evaluations (GRADE), [12] the Risk of Bias in Non-Randomized Studies of Intervention (ROBINS), [11] and the Johns Hopkins Evidence Based Practice Model for Nursing and Health Care Professionals Hierarchy of Evidence Guide (JHNEBP). [13] Given the similarities across these instruments, we selected GRADE as it is used globally, including by the World Health Organization. [14] GRADE requires a certain level of subjectivity and the employment of additional instruments to determine the risk of bias and evaluate the evidence. To simplify the screening process and reduce the risk of subjectivity across reviewers, the GRADE framework was integrated with the JHNEHBP. All frameworks used similar concepts to evaluate the strength of the evidence:

- Study type (e.g., meta-analysis, scoping review)
- Population of focus (e.g., representativeness, sample size, geography)
- Research method(s) (e.g., literature review, integrative review)
- Data source (e.g., reliability, bias, generalizability, missing data, potential confounders)
- Evidence (e.g., analytic methods used, quantitative vs qualitative analysis, significance)

The integrated screening instrument was pilot-tested and refined to ensure consistency and ease of use. The final screening method included a three-stage process: (1) Confirm the study focused on the impact or outcome of health IT; (2) Verify the article met inclusion criteria; (3) Scoring of the scientific merit of each article based on the common criteria for evaluating research that is common to PRISMA, GRADE, COCHRANE, and other recognized frameworks.

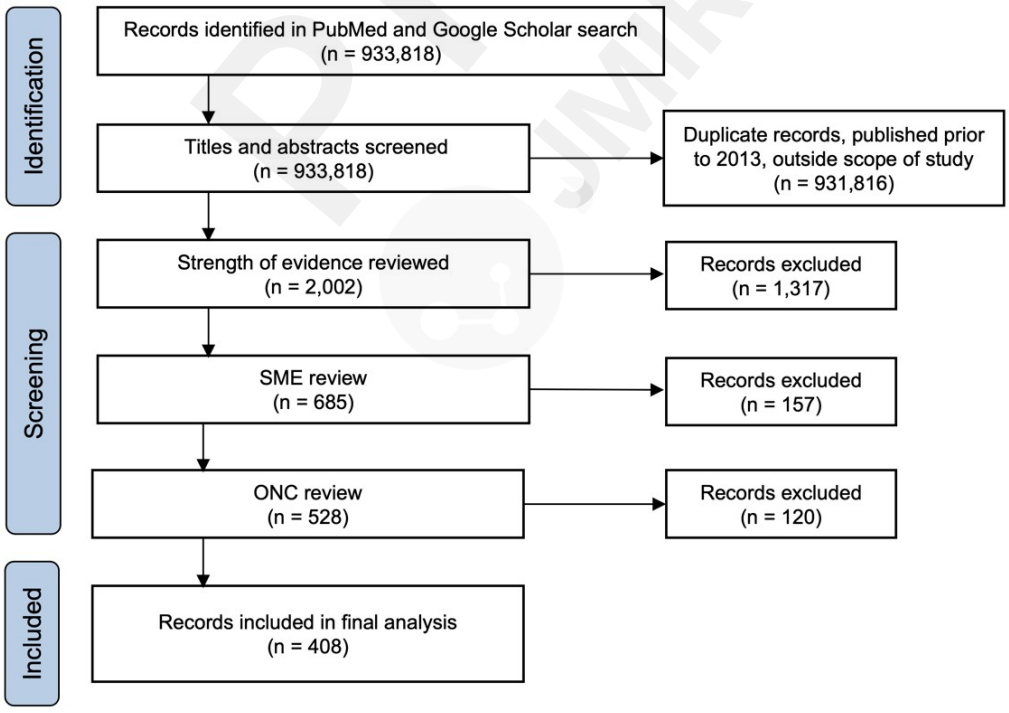
Selection Process

Similar to the process employed at the start of the systematic review, each member of the research

team assumed responsibility for assessing the scientific merit of the research based on the date of publication. As such, each reviewer including the study lead reviewed all articles from a distinct two-year period. To ensure inter-rater reliability, a random sample of articles was then re-reviewed for strength of evidence by the other members of the research team. When inconsistencies were identified, the team engaged in an open dialogue to ensure a consistent understanding and application of the criteria for assessing scientific merit.

The lead author of the study and senior officials at ONC conducted a final review to verify each article's appropriateness based on the inclusion/exclusion criteria and scientific merit while also objectively confirming the article focused on the impact of health IT. The final set of articles totaled 408. The selection process is illustrated in Figure 1.

Figure 1. Article Review and Evaluation



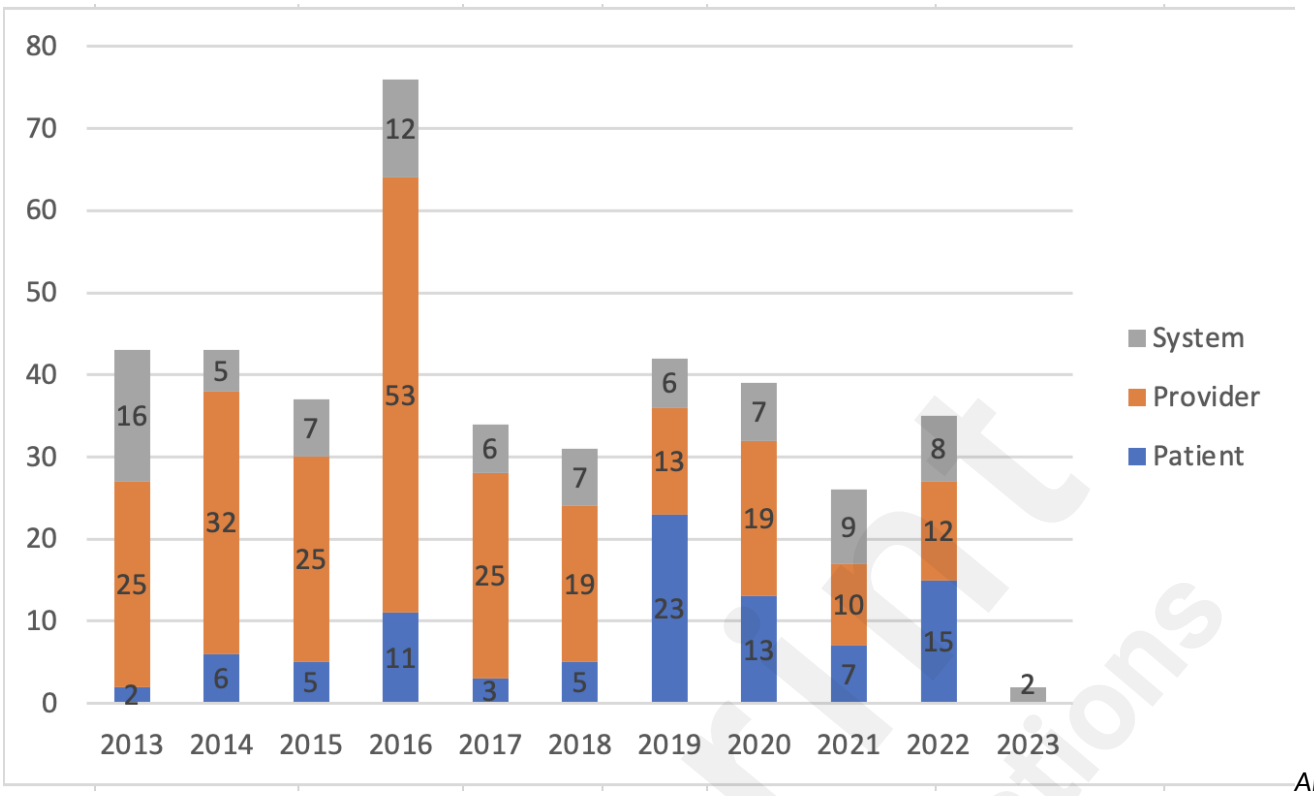
Alt Text: A flow diagram illustrating the process by which 933,818 identified articles were reviewed to reach a final of 408 articles included for analysis.

To inform the analysis, all articles were classified based on (1) the health care setting(s) in which the research was based; (2) the objective of the research as it pertains to ONC's core mission; and (3) its alignment with federal priorities as specified in the Federal Health IT Strategic Plan, 2020-2025. [15] The study team captured the final set of articles in a structured document to enable analysis.

RESULTS

Previous research has noted the increasing volume of studies focused on health IT. This review identified a similar growth in the number of published studies pertaining to health IT; however, after applying the exclusion criteria, the number of articles focused on the *impact* of health IT was relatively stable with the exception of 2016, during which the number of identified studies was nearly double that of other years (Figure 2).

Figure 2. Total Number of Health IT Articles by Year



Alt text: A stacked bar chart showing the distribution of articles by year and focus: provider, patient, system

Notes: Annual counts of health IT articles reflect only those that met the inclusion criteria established for this review. 2023 articles only reflected publications through June 2023

Studies were organized into three categories based on the focus of the article: provider-facing health IT, patient-facing technology, or based on topics that pertained to the systemwide use of health IT. The categorization of the articles by year is depicted in Table 2. Within each of these categories, articles were organized around key themes.

Articles categorized as provider-facing health IT were organized into three distinct groups that assessed health IT's impact on: (1) adoption and use; (2) measurable outcomes (e.g., safety, costs, quality); or (3) provider experience.

Research categorized as patient-facing heath IT were organized into three groups based on the how

the technology affected patients and providers. The first two categories focused on the impact of the technology on patients, distinguishing the use of patient portals, defined as tools to enable patient access to information (group 1) from more advanced patient-facing tools ranging from secure messaging to decision support to tools for patient self-management (group 2). Several articles assessing how providers and patients perceived patient-facing technology were delegated to a third group.

Studies that considered the impact of health IT on the overall health system infrastructure or operations were labeled as systemwide health IT. These were organized into two groups: (1) data interoperability, including HIEs; (2) public and/or population health.

Further analysis reviewed the cadence of the article with regards to the impact of health IT on the topic of focus.

Table 2. Topics of focus and volume of articles with positive or negative impact on outcomes

	Positive	Mixed	Neutral	Negative	Total
Provider-facing	**137 (59%)**	**43 (19%)**	**15 (6%)**	**37 (16%)**	**232**
Adoption and use	23 (52%)	13 (30%)	2 (5%)	6 (14%)	44
Health outcomes and efficiency	104 (64%)	25 (15%)	13 (8%)	20 (12%)	162
Provider experience	10 (38%)	5 (19%)	0	11 (42%)	26
Patient-facing	**54 (59%)**	**15 (16%)**	**2 (2%)**	**20 (22%)**	**91**
Portal	17 (52%)	6 (18%)	1 (3%)	9 (27%)	33
Advanced patient-facing features	26 (79%)	4 (12%)	0	3 (9%)	33
Patient and provider experience	11 (44%)	5 (20%)	1 (4%)	8 (32%)	25
Systemwide health IT	60 (71%)	13 (15%)	0 (0%)	12 (14%)	85
HIE and interoperability	35 (73%)	6 (13%)	0	7 (15%)	48
Public or population health	25 (68%)	7 (19%)	0	5 (14%)	37
TOTAL	**251 (62%)**	**71 (17%)**	**17 (4%)**	**69 (17%)**	**408**

Overall Assessment of Impact:

Overwhelmingly, research studies reported that health IT generated a positive impact (79% reported a positive or mixed impact). This finding was consistent across all topics.

An examination of the distribution of these studies indicates the positive impact of provider-facing technologies, which comprise 59% positive and 19% mixed responses out of a total of 232 studies in the category. Similarly, health IT's influence on adoption and usage is seen as favorable or mixed in 82% of the cases. When assessing the effect of health IT on measurable health outcomes and efficiency, 79% of the studies reported positive or mixed impacts. This trend underscores the pivotal role health IT plays in enhancing quality, patient safety, costs, and efficiency within health care systems. Despite this, provider experience is an area with divided outcomes, where studies reported a nearly even split between positive (38%), and negative impacts (42%), with mixed results (19%) making up the remainder.

Patient-facing technologies, which represent a critical interface between health care systems and patients, have also been subjected to academic scrutiny. Of these, technologies like patient portals are acknowledged for their positive and mixed (70%) impacts, indicative of their role in improving patient access to health data. Advanced patient-facing features such as online screening instruments or disease management tools, reflect an even greater positive outcome, with 79% of studies affirming their advantageous effects.

Accounting for one-fifth of the research studies, the systemwide health IT implications are noteworthy, with 71% positive and 15% mixed impacts reported, emphasizing the extensive

benefits of technology in enhancing the health care systems at large. Notably, HIE and interoperability studies showcase a similar trend, with 86% positive and mixed findings. The impact of systemwide health IT use on public and population health have also been evaluated, with 87% positive and mixed outcomes reported, reinforcing relatively widespread acceptance of health IT's positive role in generating systemwide benefits.

This analysis affirms the perspective that health IT has been beneficial across varied areas of health care, with consistently positive or mixed impacts reported across all topics. The continued, steady representation of articles on provider-facing technology over the past decade, the growing body of research on patient-facing technologies, and the substantial evidence of health IT's favorable impact on health systems collectively illustrate the progressive integration and essential role in enhancing health care outcomes and experiences.

Topic-specific findings

Below we discuss the overall findings in the context of the intended audience (provider or patient) or systemwide focus. Within each of the topics, we highlight key themes that emerged from the literature as well as how the research findings and foci evolved over the past decade.

Provider-Facing

While health IT affects a wide array of stakeholders, its impact on providers is pivotal given their interaction with health IT. This includes studies focused on implementation and operationalization of EHR functions, including clinical decision support (CDS), computerized provider order entry (CPOE), electronic referrals, and e-prescribing. While some studies assessed trends in technology

use, others focused on its overall impact as well as the impact on providers.

Adoption and use of health IT

Initially, a large focus of the research on provider-facing technology centered on the impact of the HITECH Act. [16,17] Articles published between 2013 and 2015 focused on the changes in EHR use following the initiation of the EHR Incentive Programs. [18-21] Beginning in 2015, research expanded from looking at the overall use of EHRs to a greater concentration on specific EHR functions including CDS and CPOE, a research topic that grew exponentially between 2015 and 2017 and remained an ongoing topic of interest. [22-37] Some studies assessed CPOE, including using CDS to support CPOE. Research also focused on e-prescribing and electronic referrals. [38-41] Since 2019, there have been fewer publications on the overall impact of EHR use; offset by an increased volume of research specifically focused on how provider-facing technology impacts clinical outcomes.

Several articles focused on the increasing adoption and use of health IT. [42,43] Many highlighted the success of federal investments; however, some articles noted low rates of adoption shortly after implementation of the EHR Incentive Programs, particularly within specific provider groups. [44,45]

Health outcomes and efficiency

Following implementation of the EHR Incentive Programs, research pivoted to studying how increased adoption affected health care delivery. Most articles highlighted health IT's impact on outcomes, including quality and safety. Others reviewed its impact on efficiency and costs. Numerous studies found that health IT use enhanced quality of care, including expanding preventive health screening. [46-48] Several articles assessed the impact of EHRs on patient safety with a particular focus on medication safety. This included the impact of specific EHR features, like CDS,

on preventing medication errors and adverse inpatient events. Multiple studies focused on CPOE evaluated its contributions to enhanced medication safety. [49-52]

EHRs' impact on cost and efficiency was a consistent area of focus. Multiple articles reported that the use of EHRs was associated with reduced hospital admissions. [53-55] Other identified efficiencies included more seamless care transitions, decreased length of stay, enhanced primary care provider productivity, and more efficient analysis of lab results. [56,57] CPOE and e-prescribing were identified as EHR features that generated efficiencies and reduced health care costs; higher use of CPOE was associated with a reduction in length of stay as well as decreased volume of labs and radiology requests. [58-60] Two studies found that e-prescribing may reduce medication costs by encouraging higher use of generic or formulary medications. [61,62]

Despite these positive findings, some studies found that health IT and EHR adoption had either a negative effect or no impact on efficiency, showing a negative impact on productivity, increased medical costs, and no impact on reducing duplicate testing. [63-65] A few articles discussed EHR-related safety concerns[66-68]; with a number of these studies attributing these problems to user design and interface. [69,70] Other studies found that EHR use initially increased costs, reduced productivity, and resulted in delays in care. [71,72] Most of these studies were published in the first few years following implementation of the EHR Incentive Programs when challenges related to costs of the EHR system, workflow redesign, and limited technical support hindered adoption efforts. [73]

Provider experience

Several studies investigated the impact of EHRs and health IT on provider experience. While one study reported higher satisfaction among providers who are more experienced using EHRs, [74] in

general, the research highlighted that adoption and use of EHRs has increased provider burden. [75,76] Many studies noted specific features of EHRs that contribute to increased burden such as the volume of alerts generated by CDS, [25,26] and the extra time required for documentation and reviewing data and reports, [27-29] Mann noted that many CDS systems are not user-centric, impacting their use. [77] This observation was supported by research showing that many providers ignore clinical alerts. [78,79] However, one study noted that, when appropriately integrated into the workflow, health IT can mitigate burnout levels. [80]

In 2020, in compliance with the 21st Century Cures Act, ONC released a report titled "Strategy on Reducing Regulatory and Administrative Burden Relating to the Use of Health IT and EHRs". [81] The report highlighted federal programs and regulations related to the use of health IT that have increased provider burden including, but not limited to, clinical documentation, health IT usability, and reporting requirements.

Patient Facing Health Technology

Research on patient-facing technology expanded over the 10-year period. Increased utilization of these technologies was spurred by higher levels of adoption of EHRs. [82] In 2013, only 40% of non-federal acute care hospitals and one third of office-based physicians were using an EHR that enabled patient access to their heath information. Since that time, the number of patients offered access to their medical record has more than doubled. [30]

Portals

Research focused on patient portals grew substantially beginning in 2018. These studies depicted portals as electronic tools to enable patients to access their health information including test results

and provider clinical notes. [83,84] Several studies emphasized the value of patient portals in increasing engagement. [31,85] In addition to accessing personal health data, patients used portals to coordinate care for family members. [31,86,87]

Several studies highlighted the positive impact of patient portals on patient self-management and care coordination across a range of conditions. [88-90] Studies also found that increased portal use was associated with higher rates of preventive care and medication compliance. [30,32] Contrary to these findings, some studies concluded that there is insufficient evidence that increased use of patient portals positively impacts clinical outcomes and efficiency. [91-93]

Several studies called attention to the impact of electronic portals on health disparities with reduced access and/or lower utilization among non-white males and uninsured or publicly insured individuals. [94-97] Higher utilization of portals, resulting in increased patient engagement, was associated with sociodemographic characteristics such as age and race but also impacted by factors associated with the technology including the usability of the platform and the digital literacy of the patient. [98-100]

Advanced patient-facing features

Research indicated that patient access to health information and additional tools, like secure messaging, enhance patient engagement and outcomes. In particular, secure messaging was linked to improved healthcare participation. [33,101] Other effective features included online screening, medication refills, and appointment scheduling tools, along with decision support for self-care and bidirectional portals for sharing personal health information. [102-106]

The use of patient-facing technology generated efficiencies of care and costs savings. Studies noted that greater use of patient-facing technology reduced costs for substance use treatment and decreased missed appointments and emergency room visits. [84,102,107,108]

Several studies noted the impact of patient-facing tools on health disparities. Specifically, individuals with fewer financial resources, patients with less education, older adults, and racial and ethnic minority groups were less likely to access, and thus benefit from, patient engagement tools. [96,109-111] The resulting disparity in patient engagement resulting from use of electronic patient-facing tools may be perpetuated by providers as patients from racial and ethnic minority populations, those with lower income, and individuals living in rural areas were less likely to be offered access to their online medical information via a patient portal. [82,112] Given the findings that greater use of patient-facing health technology is associated with increased patient engagement and improvements in care management and health outcomes, these differences are likely to exacerbate health disparities absent focused efforts to address these systemic challenges.

Patient and provider experience

Overarchingly, studies found that patients valued the use of patient-facing technology to engage in their health care. [113,114] Both patients and providers agreed that these tools enabled better communication. [115-117] Patients who expressed dissatisfaction with patient-facing technology cited concerns regarding the complexity of the technology. [118,119] Additionally, a study noted that online tools may lack sufficient explanatory information. [120]

Systemwide Health IT

As adoption has increased, so have studies on the systemwide impact of health IT. More than one in

five articles considered the impact of technology that shared or aggregated health data.

HIE and Interoperability

Across the decade, studies on HIE highlighted the importance of data exchange and interoperability. Many publications detailed evidence of the impact of information exchange on quality and costs. [34-36] This included highlighting the benefits of HIE participation including: reduced duplication of tests, decreased emergency department use, improvements in primary and preventive care, enhanced care coordination, and reduced hospital length of stay. [121-125] Other studies highlighted national efforts to advance interoperability including the Veterans Lifetime Electronic Record Health Exchange, the Nationwide Health Information Network, and private enterprise HIEs. [36,126-128] Some studies noted specific limitations of HIEs including low levels of data exchange or limitations in their configuration or usability. However, many of these articles were published between 2014-2016, prior to increased certification requirements and provisions to advance interoperable exchange. [129-133]

Public and Population Health

Health IT is recognized for its potential to advance population and public health. Its value lies in supporting disease surveillance and tracking population health. [134,135] Early research focused on the quality of EHR data for population health efforts, later shifting to health IT's advanced uses in patient screening and public health surveillance. [136-139] Recent work has shown its effectiveness in tracking adverse drug events and reporting to public health agencies. [140,141]

Research affirmed that health IT has a positive impact on public health, utilizing advanced features like dashboards and complex algorithms to improve outcomes for chronic disease. [142-144] During the

COVID-19 pandemic, health IT was an effective tool to support symptom surveillance, screening, and data reporting. [145]

Challenges persist regarding data quality and comprehensiveness and inconsistencies in data extraction and use, affecting its utility in public health activities. [146-148] Shah and Dhakal noted difficulties in data sharing with public health departments and using laboratory data for biosurveillance. [147,149]

DISCUSSION

Over the past decade, the focus of studies on health IT's impact has evolved, transitioning from a concentration on health IT adoption to a broader evaluation of how it can be optimized to improve health care efficiency, costs, safety, and quality.

In the first part of the decade, research concentrated on the technical implementation and system interoperability of EHRs. The primary goal was to transition from paper-based health records to digital platforms, ensuring seamless data exchange across various medical institutions. The emphasis was on developing standardized data formats, efficient data storage solutions, and addressing the initial resistance from healthcare providers wary of transitioning from the traditional methods they were accustomed to.

As EHR systems became more widespread and integrated into daily clinical practice, more research focused on understanding their impact on clinical outcomes, patient safety, and healthcare delivery efficiency. Studies began examining how EHRs could be leveraged for clinical decision support,

enhancing patient-provider communication, and facilitating coordinated care. Simultaneously, concerns arose regarding data privacy, security, and the potential for EHR-induced errors. Research started delving into these challenges, aiming to balance the benefits of digitized health records and the potential risks they posed.

In recent years, with the maturation of EHR systems and their near-ubiquitous adoption in healthcare settings, research has taken a more nuanced approach. Contemporary studies are examining the socio-technical aspects of EHRs, understanding the human factors that influence their use, and exploring ways to optimize their functionalities to cater to the evolving needs of both providers and patients. There's also an increasing emphasis on leveraging the vast amounts of data stored in EHRs for predictive analytics, population health management, and personalized medicine, marking a transition from reactive to proactive healthcare delivery.

The tenor of the articles also shifted over time with an increase in those reporting a positive impact as the years progress. This trend included research findings that electronic health systems and health information exchange were improving access, quality, and reducing costs; patient facing technology including patient portals were increasingly being used by consumers; and electronic health data, supported by information exchange, has a growing role in supporting and advancing public and population health.

CONCLUSION

This paper provides a comprehensive overview of changes in the health IT landscape over the past decade. The findings highlight the evolving role of health IT and its impact on people, processes,

and outcomes. Research studies depict a changing landscape with an increased focus on health IT's impact on measurable outcomes, patient engagement, and optimization of the health care system.

Despite the breath of topics covered over the ten years, there remain areas where more research is needed. These include a more comprehensive understanding of the benefits of health IT to advance population health, barriers to the exchange of health information with public health departments and related entities, and interventions to address the impact of health IT on health disparities. Health IT is rapidly changing with an increasing focus on more advanced features and ways of using technology to advance health care. Future research will provide additional insights to better understand these and other important impacts of health IT.

In the post COVID era, there is greater recognition of the importance of health IT in supporting health care and public health outcomes, including disease management, preventive care, and emergency planning.

The role of policy-making bodies, particularly ONC, will be pivotal in shaping the future trajectory of EHR, interoperability, and health IT research. ONC policies, especially those centered around interoperability requirements, and expanded health IT use cases (i.e., public health IT, electronic prior authorization), will provide the framework for future research. As ONC pushes for a more inclusive, patient-centered, and interoperable health IT ecosystem, research will inevitably focus on these areas, striving to align technological advancements with policy directives. The harmonization of policy and research will be instrumental in ensuring that EHRs and health IT evolve to meet the dynamic needs of the healthcare sector, ultimately benefiting both providers and the patients they serve.

Investments, program enhancements, and new policies should be informed by the research studies published over the past decade. Investments should build upon these insights, aligning with ONC's mission and strategic goals.

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Conflicts of Interest

The authors do not have any conflicts of interest to report.

References

1. (HHS) TUSDoHaHS. *Federal Health IT Strategic Plan*. 2005. https://www.healthit.gov/topic/2020-2025-federal-health-it-strategic-plan
2. (ONC) Office of the National Coordinator for Health IT. *FY 2008 Annual Performance Report*. 2007. https://www.healthit.gov/sites/default/files/page/2020-02/BurdenReport_0.pdf
3. Heisey-Grove D, Danehy LN, Consolazio M, Lynch K, Mostashari F. A national study of challenges to electronic health record adoption and meaningful use. *Med Care*. Feb 2014;52(2):144-8. doi:10.1097/mlr.0000000000000038
4. Chaudhry B, Wang J, Wu S, et al. Systematic review: impact of health information technology on quality, efficiency, and costs of medical care. *Ann Intern Med*. May 16 2006;144(10):742-52. doi:10.7326/0003-4819-144-10-200605160-00125
5. Goldzweig CL, Towfigh A, Maglione M, Shekelle PG. Costs and benefits of health information technology: new trends from the literature. *Health Aff (Millwood)*. Mar-Apr 2009;28(2):w282-93. doi:10.1377/hlthaff.28.2.w282
6. 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)*. Mar 2011;30(3):464-71. doi:10.1377/hlthaff.2011.0178
7. Ash JS, Bates DW. Factors and forces affecting EHR system adoption: report of a 2004 ACMI discussion. *J Am Med Inform Assoc*. Jan-Feb 2005;12(1):8-12. doi:10.1197/jamia.M1684
8. Jones SS, Rudin RS, Perry T, Shekelle PG. Health information technology: an updated systematic review with a focus on meaningful use. *Ann Intern Med*. Jan 7 2014;160(1):48-54. doi:10.7326/M13-1531
9. (CMS) Centers for Medicare & Medicad Services. Promoting Interoperability Programs. 2024. https://www.cms.gov/medicare/regulations-guidance/promoting-interoperability-programs#:~:text=In%202011%2C%20the%20Centers%20for,and%20demonstrate%20meaningful%20use%20ofbuntin
10. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *PLOS Medicine*. 2021;18(3):e1003583. doi:10.1371/journal.pmed.1003583
11. Higgins JPT TJ, Chandler J, Cumpston M, Li T, Page MJ, Welch VA. Cochrane Handbook for Systematic Reviews of Interventions version 6.4 (updated August 2023).
12. GRADE handbook for grading quality of evidence and strength of recommendations. 2013. guidelinedevelopment.org/handbook
13. Dang D, Dearholt, S., Bissett, K., Ascenzi, J., & Whalen, M. Johns Hopkins evidence-based practice for nurses and healthcare professionals: Model and guidelines. *Sigma Theta Tau International*. 2022;4
14. Dewidar O, Lotfi T, Langendam MW, et al. Good or best practice statements: proposal for the operationalisation and implementation of GRADE guidance. *BMJ Evid Based Med*. Jun 2023;28(3):189-196. doi:10.1136/bmjebm-2022-111962
15. (HHS) U.S. Department of Health and Human Services/ Office of the National Coordinator for Health IT. *2020-2025 Federal Health IT Strategic Plan*. 2020.

https://www.healthit.gov/topic/2020-2025-federal-health-it-strategic-plan

16. Khaliq AA, Mwachofi AK, Hughes DR, Broyles RW, Wheeler D, Roswell RH. The current state of electronic health record (EHR) use in Oklahoma. *J Okla State Med Assoc*. Feb 2013;106(2):53-6.

17. Ryan J, Doty MM, Abrams MK, Riley P. *The Adoption and Use of Health Information Technology by Community Health Centers, 2009–2013*. 2014. https://www.commonwealthfund.org/sites/default/files/documents/___media_files_publications_issue_brief_2014_may_1746_ryan_adoption_use_hlt_it_chcs_rb.pdf

18. Ahmad FS, Tsang T. Diabetes Prevention, Health Information Technology, and Meaningful Use: Challenges and Opportunities. *American Journal of Preventive Medicine*. 2013;44(4):S357-S363. doi:10.1016/j.amepre.2012.12.020

19. Adler-Milstein J, Huckman RS. The impact of electronic health record use on physician productivity. *The American journal of managed care*. 2013/11// 2013;19(10 Spec No):SP345-52.

20. McLaughlin CG, Lammers E. Geographic variation in health IT and health care outcomes: A snapshot before the meaningful use incentive program began. *Healthc (Amst)*. Mar 2015;3(1):18-23. doi:10.1016/j.hjdsi.2014.05.003

21. Soteriades ES, Talias MA, Harmon KT, Schumann SC, Kales SN. Electronic medical record use among US occupational medicine physicians: a national survey. *J Occup Environ Med*. Oct 2013;55(10):1191-6. doi:10.1097/JOM.0b013e31829b3a4c

22. Lacson R, O'Connor SD, Sahni VA, et al. Impact of an electronic alert notification system embedded in radiologists' workflow on closed-loop communication of critical results: a time series analysis. *BMJ Qual Saf*. Jul 2016;25(7):518-24. doi:10.1136/bmjqs-2015-004276

23. Amland RC, Hahn-Cover KE. Clinical Decision Support for Early Recognition of Sepsis. *Am J Med Qual*. Mar-Apr 2016;31(2):103-10. doi:10.1177/1062860614557636

24. Schiff GD, Volk LA, Volodarskaya M, et al. Screening for medication errors using an outlier detection system. *Journal of the American Medical Informatics Association*. 2017;24(2):281-287. doi:10.1093/jamia/ocw171

25. Chaparro JD, Hussain C, Lee JA, Hehmeyer J, Nguyen M, Hoffman J. Reducing Interruptive Alert Burden Using Quality Improvement Methodology. *Appl Clin Inform*. 2020/01/15 2020;11(01):046-058. doi:10.1055/s-0039-3402757

26. Dexheimer JW, Kirkendall ES, Kouril M, et al. The Effects of Medication Alerts on Prescriber Response in a Pediatric Hospital. *Appl Clin Inform*. 2017/12/21 2017;08(02):491-501. doi:10.4338/ACI-2016-10-RA-0168

27. Young RA, Burge SK, Kumar KA, Wilson JM, Ortiz DF. A Time-Motion Study of Primary Care Physicians' Work in the Electronic Health Record Era. 2018;

28. Vahdat V, Griffin JA, Stahl JE, Yang FC. Analysis of the effects of EHR implementation on timeliness of care in a dermatology clinic: a simulation study. *Journal of the American Medical Informatics Association*. 2018;25(7):827-832. doi:10.1093/jamia/ocy024

29. Attipoe S, Hoffman J, Rust S, et al. Characterization of Electronic Health Record Use Outside Scheduled Clinic Hours Among Primary Care Pediatricians: Retrospective Descriptive Task Analysis of Electronic Health Record Access Log Data. *JMIR Med Inform*. 2022/5/12 2022;10(5):e34787. doi:10.2196/34787

30. Richwine C, Barker W, Everson J, Patel V. A Decade of Data Examined: Patient Access to Electronic Health Information.

31. Reed ME, Huang J, Brand RJ, et al. Patients with complex chronic conditions: Health care use and clinical events associated with access to a patient portal. *PLoS One*. 2019;14(6):e0217636. doi:10.1371/journal.pone.0217636

32. Han H-R, Gleason KT, Sun C-A, et al. Using Patient Portals to Improve Patient Outcomes: Systematic Review. *JMIR Hum Factors*. 2019/12/19 2019;6(4):e15038. doi:10.2196/15038

33. Heisey-Grove DM, Carretta HJ. Disparities in Secure Messaging Uptake Between Patients and Physicians: Longitudinal Analysis of Two National Cross-Sectional Surveys. *J Med Internet Res*. 2020/5/1 2020;22(5):e12611. doi:10.2196/12611

34. Bailey LC, Milov DE, Kelleher K, et al. Multi-Institutional Sharing of Electronic Health Record Data to Assess Childhood Obesity. *PLOS ONE*. 2013;8(6):e66192. doi:10.1371/journal.pone.0066192

35. O'Malley AS, Reschovsky JD, Saiontz-Martinez C. Interspecialty communication supported by health information technology associated with lower hospitalization rates for ambulatory care-sensitive conditions. *J Am Board Fam Med*. May-Jun 2015;28(3):404-17. doi:10.3122/jabfm.2015.03.130325

36. Adjerid I, Adler-Milstein J, Angst C. Reducing Medicare Spending Through Electronic Health Information Exchange: The Role of Incentives and Exchange Maturity. *Information Systems Research*. 2018/06/01 2018;29(2):341-361. doi:10.1287/isre.2017.0745

37. Vest JR, Freedman S, Unruh MA, Bako AT, Simon K. Strategic use of health information exchange and market share, payer mix, and operating margins. *Health Care Manage Rev*. Jan-Mar 01 2022;47(1):28-36. doi:10.1097/hmr.0000000000000293

38. Saiyed SM, Greco PJ, Fernandes G, Kaelber DC. Optimizing drug-dose alerts using commercial software throughout an integrated health care system. *Journal of the American Medical Informatics Association*. 2017;24(6):1149-1154. doi:10.1093/jamia/ocx031

39. Prgomet M, Li L, Niazkhani Z, Georgiou A, Westbrook JI. Impact of commercial computerized provider order entry (CPOE) and clinical decision support systems (CDSSs) on medication errors, length of stay, and mortality in intensive care units: a systematic review and meta-analysis. *Journal of the American Medical Informatics Association*. 2016;24(2):413-422. doi:10.1093/jamia/ocw145

40. Abramson EL. Causes and consequences of e-prescribing errors in community pharmacies. *Integr Pharm Res Pract*. 2015;5:31-38. doi:10.2147/iprp.S64927

41. Scheibe MM, Imboden JB, Schmajuk G, et al. Efficiency Gains for Rheumatology Consultation Using a Novel Electronic Referral System in a Safety-Net Health Setting. *Arthritis Care Res (Hoboken)*. Aug 2015;67(8):1158-63. doi:10.1002/acr.22559

42. Appari A, Eric Johnson M, Anthony DL. Meaningful Use of Electronic Health Record Systems and Process Quality of Care: Evidence from a Panel Data Analysis of U.S. Acute-Care Hospitals. *Health Services Research*. 2013;48(2pt1):354-375. doi:https://doi.org/10.1111/j.1475-6773.2012.01448.x

43. Cho NE, Chang J, Atems B. The effects of health information technology adoption and hospital-

physician integration on hospital efficiency. *Am J Manag Care*. Nov 2014;20(11 Spec No. 17):eSP9-eSP15.

44. Dowling RA. Health Information Technology in Urologic Care: Current Status and Implications for Quality of Care. *Current Urology Reports*. 2013/12/01 2013;14(6):535-540. doi:10.1007/s11934-013-0356-3

45. Narcisse M-R, Kippenbrock TA, Odell E, Buron B. Advanced Practice Nurses' Meaningful use of electronic health records. *Applied Nursing Research*. 2013/08/01/ 2013;26(3):127-132. doi:https://doi.org/10.1016/j.apnr.2013.02.003

46. Williams C, Asi Y, Raffenaud A, Bagwell M, Zeini I. The effect of information technology on hospital performance. *Health Care Manag Sci*. Dec 2016;19(4):338-346. doi:10.1007/s10729-015-9329-z

47. Ford EW, Silvera GA, Kazley AS, Diana ML, Huerta TR. Assessing the relationship between patient safety culture and EHR strategy. *Int J Health Care Qual Assur*. Jul 11 2016;29(6):614-27. doi:10.1108/ijhcqa-10-2015-0125

48. Furukawa MF, Spector WD, Rhona Limcangco M, Encinosa WE. Meaningful use of health information technology and declines in in-hospital adverse drug events. *J Am Med Inform Assoc*. Jul 1 2017;24(4):729-736. doi:10.1093/jamia/ocw183

49. Seidling HM, Bates DW. Evaluating the Impact of Health IT on Medication Safety. *Stud Health Technol Inform*. 2016;222:195-205.

50. Campanella P, Lovato E, Marone C, et al. The impact of electronic health records on healthcare quality: a systematic review and meta-analysis. *Eur J Public Health*. Feb 2016;26(1):60-4. doi:10.1093/eurpub/ckv122

51. Melton BL, Zillich AJ, Russell SA, et al. Reducing prescribing errors through creatinine clearance alert redesign. *Am J Med*. Oct 2015;128(10):1117-25. doi:10.1016/j.amjmed.2015.05.033

52. Stultz JS, Nahata MC. Complexities of Clinical Decision Support Illustrated by Pediatric Dosing Alerts. *Ann Pharmacother*. Nov 2015;49(11):1261-4. doi:10.1177/1060028015604632

53. Kazley AS, Simpson AN, Simpson KN, Teufel R. Association of electronic health records with cost savings in a national sample. *Am J Manag Care*. Jun 1 2014;20(6):e183-90.

54. Hessels A, Flynn L, Cimiotti JP, Bakken S, Gershon R. Impact of Heath Information Technology on the Quality of Patient Care. *Online J Nurs Inform*. Fall 2015;19

55. Matiz LA, Robbins-Milne L, Krause MC, Peretz PJ, Rausch JC. Evaluating the Impact of Information Technology Tools to Support the Asthma Medical Home. *Clin Pediatr (Phila)*. Feb 2016;55(2):165-70. doi:10.1177/0009922815596070

56. Huber TP, Shortell SM, Rodriguez HP. Improving Care Transitions Management: Examining the Role of Accountable Care Organization Participation and Expanded Electronic Health Record Functionality. *Health Serv Res*. Aug 2017;52(4):1494-1510. doi:10.1111/1475-6773.12546

57. Young PE, Diaz GJ, Kalariya RN, et al. Comparison of the time required for manual (visually read) and semi-automated POCT urinalysis and pregnancy testing with associated electronic medical record (EMR) transcription errors. *Clinica Chimica Acta*. 2020/05/01/ 2020;504:60-63. doi:https://doi.org/10.1016/j.cca.2020.01.021

58. Schreiber R, Shaha SH. Computerised Provider Order Entry Adoption Rates Favourably Impact

Length of Stay. *J Innov Health Inform*. Apr 18 2016;23(1):166. doi:10.14236/jhi.v23i1.166

59. Algaze CA, Wood M, Pageler NM, Sharek PJ, Longhurst CA, Shin AY. Use of a Checklist and Clinical Decision Support Tool Reduces Laboratory Use and Improves Cost. *Pediatrics*. Jan 2016;137(1)doi:10.1542/peds.2014-3019

60. Claret PG, Bobbia X, Macri F, et al. Impact of a computerized provider radiography order entry system without clinical decision support on emergency department medical imaging requests. *Comput Methods Programs Biomed*. Jun 2016;129:82-8. doi:10.1016/j.cmpb.2016.03.006

61. Malhotra S, Cheriff AD, Gossey JT, Cole CL, Kaushal R, Ancker JS. Effects of an e-Prescribing interface redesign on rates of generic drug prescribing: exploiting default options. *J Am Med Inform Assoc*. Sep 2016;23(5):891-8. doi:10.1093/jamia/ocv192

62. Richman M, Joo J, Rohani P. Transitioning to E-Prescribing: Preformatted Prescription Forms Improve Safety, Formulary Compliance, Prescribing Satisfaction, and Perceived Efficiency. *Journal of Patient Safety*. 2018;14(4)

63. Redd TK, Read-Brown S, Choi D, Yackel TR, Tu DC, Chiang MF. Electronic health record impact on productivity and efficiency in an academic pediatric ophthalmology practice. *Journal of American Association for Pediatric Ophthalmology and Strabismus {JAAPOS}*. 2014;18(6):584-589. doi:10.1016/j.jaapos.2014.08.002

64. Agha L. The effects of health information technology on the costs and quality of medical care. *Journal of Health Economics*. 2014/03/01/ 2014;34:19-30. doi:https://doi.org/10.1016/j.jhealeco.2013.12.005

65. Kerwin TC, Leighton H, Buch K, Avezbadalov A, Kianfar H. The Effect of Adoption of an Electronic Health Record on Duplicate Testing. *Cardiol Res Pract*. 2016;2016:1950191. doi:10.1155/2016/1950191

66. Meeks DW, Smith MW, Taylor L, Sittig DF, Scott JM, Singh H. An analysis of electronic health record-related patient safety concerns. *Journal of the American Medical Informatics Association*. 2014;21(6):1053-1059. doi:10.1136/amiajnl-2013-002578

67. Coiera E, Ash J, Berg M. The Unintended Consequences of Health Information Technology Revisited. *Yearb Med Inform*. Nov 10 2016;(1):163-169. doi:10.15265/iy-2016-014

68. Sakata KK, Stephenson LS, Mulanax A, et al. Professional and interprofessional differences in electronic health records use and recognition of safety issues in critically ill patients. *J Interprof Care*. Sep 2016;30(5):636-42. doi:10.1080/13561820.2016.1193479

69. Bowman S. Impact of electronic health record systems on information integrity: quality and safety implications. *Perspect Health Inf Manag*. 2013;10(Fall):1c.

70. Ratwani RM, Savage E, Will A, et al. Identifying Electronic Health Record Usability And Safety Challenges In Pediatric Settings. *Health Affairs*. 2018/11/01 2018;37(11):1752-1759. doi:10.1377/hlthaff.2018.0699

71. Fleming NS, Becker ER, Culler SD, et al. The Impact of Electronic Health Records on Workflow and Financial Measures in Primary Care Practices. *Health Services Research*. 2014;49(1pt2):405-420. doi:https://doi.org/10.1111/1475-6773.12133

72. Kim MO, Coiera E, Magrabi F. Problems with health information technology and their effects on care delivery and patient outcomes: a systematic review. *Journal of the American Medical*

Informatics Association. 2017;24(2):246-250. doi:10.1093/jamia/ocw154

73. Kruse CS, Kristof C, Jones B, Mitchell E, Martinez A. Barriers to Electronic Health Record Adoption: a Systematic Literature Review. *J Med Syst*. Dec 2016;40(12):252. doi:10.1007/s10916-016-0628-9

74. Kissel AM, Maddox K, Francis JKR, et al. Effectsoftheelectronichealth record onjob satisfactionofacademic pediatric faculty. *International Journal of Medical Informatics*. 2022/12/01/ 2022;168:104881. doi:https://doi.org/10.1016/j.ijmedinf.2022.104881

75. Gregory ME, Russo E, Singh H. Electronic Health Record Alert-Related Workload as a Predictor of Burnout in Primary Care Providers. *Appl Clin Inform*. 2017/12/20 2017;08(03):686-697. doi:10.4338/ACI-2017-01-RA-0003

76. Meyerhoefer CD, Sherer SA, Deily ME, et al. Provider and patient satisfaction with the integration of ambulatory and hospital EHR systems. *J Am Med Inform Assoc*. Aug 1 2018;25(8):1054-1063. doi:10.1093/jamia/ocy048

77. Mann D, Hess R, McGinn T, et al. Adaptive design of a clinical decision support tool: What the impact on utilization rates means for future CDS research. *DIGITAL HEALTH*. 2019;5:2055207619827716. doi:10.1177/2055207619827716

78. Jones BE, Collingridge DS, Vines CG, et al. CDS in a Learning Health Care System: Identifying Physicians' Reasons for Rejection of Best-Practice Recommendations in Pneumonia through Computerized Clinical Decision Support. *Appl Clin Inform*. 2019/01/02 2019;10(01):001-009. doi:10.1055/s-0038-1676587

79. Topaz M, Seger DL, Slight SP, et al. Rising drug allergy alert overrides in electronic health records: an observational retrospective study of a decade of experience. *J Am Med Inform Assoc*. May 2016;23(3):601-8. doi:10.1093/jamia/ocv143

80. Wu DTY, Xu C, Kim A, Bindhu S, Mah KE, Eckman MH. A Scoping Review of Health Information Technology in Clinician Burnout. *Appl Clin Inform*. May 2021;12(3):597-620. doi:10.1055/s-0041-1731399

81. (ONC) OotNCfHIT. *Strategy on Reducing Regulatory and Administrative Burden Relating to the Use of Health IT and EHRs, Final Report*. 2020. https://www.healthit.gov/sites/default/files/page/2020-02/BurdenReport_0.pdf

82. Rodriguez ES. Using Patient Portals to Increase Engagement in Patients with Cancer. *Seminars in Oncology Nursing*. 2018/05/01/ 2018;34(2):177-183. doi:https://doi.org/10.1016/j.soncn.2018.03.009

83. Huang J, Chen Y, Landis JR, Mahoney KB. Difference Between Users and Nonusers of a Patient Portal in Health Behaviors and Outcomes: Retrospective Cohort Study. *J Med Internet Res*. 2019/10/7 2019;21(10):e13146. doi:10.2196/13146

84. Blease CR, Walker J, Torous J, O'Neill S. Sharing Clinical Notes in Psychotherapy: A New Tool to Strengthen Patient Autonomy. Opinion. *Frontiers in Psychiatry*. 2020-October-28 2020;11doi:10.3389/fpsyt.2020.527872

85. Wright JA, Volkman JE, Leveille SG, Amante DJ. Predictors of Online Patient Portal Use Among a Diverse Sample of Emerging Adults: Cross-sectional Survey. *JMIR Form Res*. 2022/2/15 2022;6(2):e33356. doi:10.2196/33356

86. Sulieman L, Steitz B, Rosenbloom ST. Analysis of Employee Patient Portal Use and Electronic Health Record Access at an Academic Medical Center. *Appl Clin Inform*. 2020/06/17 2020;11(03):433-441. doi:10.1055/s-0040-1713412

87. Hagström J, Blease C, Haage B, Scandurra I, Hansson S, Hägglund M. Views, Use, and Experiences of Web-Based Access to Pediatric Electronic Health Records for Children, Adolescents, and Parents: Scoping Review. *J Med Internet Res*. 2022/11/22 2022;24(11):e40328. doi:10.2196/40328

88. Coughlin SS, Caplan L, Young L. A Review of Web Portal Use by Oncology Patients. *J Cancer Treatment Diagn*. 2018;2(6)doi:10.29245/2578-2967/2018/6.1154

89. Dharod A, Bellinger C, Foley K, Case LD, Miller D. The Reach and Feasibility of an Interactive Lung Cancer Screening Decision Aid Delivered by Patient Portal. *Appl Clin Inform*. 2019/01/09 2019;10(01):019-027. doi:10.1055/s-0038-1676807

90. Schember CO, Scott SE, Jenkins CA, et al. Electronic Patient Portal Access, Retention in Care, and Viral Suppression Among People Living With HIV in Southeastern United States: Observational Study. *JMIR Med Inform*. 2022/7/25 2022;10(7):e34712. doi:10.2196/34712

91. Davis Giardina T, Menon S, Parrish DE, Sittig DF, Singh H. Patient access to medical records and healthcare outcomes: a systematic review. *Journal of the American Medical Informatics Association*. 2013;21(4):737-741. doi:10.1136/amiajnl-2013-002239

92. Kruse CS, Argueta DA, Lopez L, Nair A. Patient and Provider Attitudes Toward the Use of Patient Portals for the Management of Chronic Disease: A Systematic Review. *J Med Internet Res*. 2015/02/20 2015;17(2):e40. doi:10.2196/jmir.3703

93. Davis S, Roudsari A, Raworth R, Courtney KL, MacKay L. Shared decision-making using personal health record technology: a scoping review at the crossroads. *Journal of the American Medical Informatics Association*. 2017;24(4):857-866. doi:10.1093/jamia/ocw172

94. Bush RA, Vemulakonda VM, Richardson AC, Deakyne Davies SJ, Chiang GJ. Providing Access: Differences in Pediatric Portal Activation Begin at Patient Check-in. *Appl Clin Inform*. 2019/09/11 2019;10(04):670-678. doi:10.1055/s-0039-1695792

95. Wedd J, Basu M, Curtis LM, et al. Racial, Ethnic, and Socioeconomic Disparities in Web-Based Patient Portal Usage Among Kidney and Liver Transplant Recipients: Cross-Sectional Study. *J Med Internet Res*. 2019/04/22 2019;21(4):e11864. doi:10.2196/11864

96. Jella TK, Cwalina TB, Sachdev RR, Otteson T, Fowler N. Sociodemographic disparities in the use of health information technology by a national sample of head and neck cancer patients. *American Journal of Otolaryngology*. 2022/03/01/ 2022;43(2):103308. doi:https://doi.org/10.1016/j.amjoto.2021.103308

97. Sun EY, Alvarez C, Callahan LF, Sheikh SZ. The Disparities in Patient Portal Use Among Patients With Rheumatic and Musculoskeletal Diseases: Retrospective Cross-sectional Study. *J Med Internet Res*. Aug 31 2022;24(8):e38802. doi:10.2196/38802

98. Mackert M, Mabry-Flynn A, Champlin S, Donovan EE, Pounders K. Health Literacy and Health Information Technology Adoption: The Potential for a New Digital Divide. *J Med Internet Res*. Oct 4 2016;18(10):e264. doi:10.2196/jmir.6349

99. Di Tosto G, Walker DM, Sieck CJ, et al. Examining the Relationship between Health Literacy,

Health Numeracy, and Patient Portal Use. *Appl Clin Inform*. 2022/07/06 2022;13(03):692-699. doi:10.1055/s-0042-1751239

100. Sun R, Korytkowski MT, Sereika SM, Saul MI, Li D, Burke LE. Patient Portal Use in Diabetes Management: Literature Review. *JMIR Diabetes*. 2018/11/06 2018;3(4):e11199. doi:10.2196/11199

101. Cronin RM, Davis SE, Shenson JA, Chen Q, Rosenbloom ST, Jackson GP. Growth of Secure Messaging Through a Patient Portal as a Form of Outpatient Interaction across Clinical Specialties. *Appl Clin Inform*. 2015;6(2):288-304. doi:10.4338/aci-2014-12-ra-0117

102. Leanza F, Hauser D. Teens, Technology, and Health Care. *Primary Care: Clinics in Office Practice*. 2014/09/01/ 2014;41(3):559-566. doi:https://doi.org/10.1016/j.pop.2014.05.006

103. Chung S, Martinez MC, Frosch DL, Jones VG, Chan AS. Patient-Centric Scheduling With the Implementation of Health Information Technology to Improve the Patient Experience and Access to Care: Retrospective Case-Control Analysis. *J Med Internet Res*. 2020/6/10 2020;22(6):e16451. doi:10.2196/16451

104. Schoenhaus R, Lustig A, Rivas S, Monrreal V, Jr., Westrich KD, Dubois RW. Using an Electronic Medication Refill System to Improve Provider Productivity in an Accountable Care Setting. *J Manag Care Spec Pharm*. Mar 2016;22(3):204-8. doi:10.18553/jmcp.2016.22.3.204

105. Ginting K, Stolfi A, Wright J, Omoloja A. Patient Portal, Patient-Generated Images, and Medical Decision-Making in a Pediatric Ambulatory Setting. *Appl Clin Inform*. 2020/11/18 2020;11(05):764-768. doi:10.1055/s-0040-1718754

106. Liu AW, Odisho AY, Brown Iii W, Gonzales R, Neinstein AB, Judson TJ. Patient Experience and Feedback After Using an Electronic Health Record–Integrated COVID-19 Symptom Checker: Survey Study. *JMIR Hum Factors*. 2022/9/13 2022;9(3):e40064. doi:10.2196/40064

107. Pradhan AM, Park L, Shaya FT, Finkelstein J. Consumer Health Information Technology in the Prevention of Substance Abuse: Scoping Review. *J Med Internet Res*. 2019/01/30 2019;21(1):e11297. doi:10.2196/11297

108. Tsai R, Bell EJ, III, Woo H, Baldwin K, Pfeffer MA. How Patients Use a Patient Portal: An Institutional Case Study of Demographics and Usage Patterns. *Appl Clin Inform*. 2019/02/06 2019;10(01):096-102. doi:10.1055/s-0038-1677528

109. Sadasivaiah S, Lyles CR, Kiyoi S, Wong P, Ratanawongsa N. Disparities in Patient-Reported Interest in Web-Based Patient Portals: Survey at an Urban Academic Safety-Net Hospital. *J Med Internet Res*. 2019/03/26 2019;21(3):e11421. doi:10.2196/11421

110. Foster B, Krasowski MD. The Use of an Electronic Health Record Patient Portal to Access Diagnostic Test Results by Emergency Patients at an Academic Medical Center: Retrospective Study. *J Med Internet Res*. 2019/06/28 2019;21(6):e13791. doi:10.2196/13791

111. Turer RW, Martin KR, Courtney DM, et al. Real-Time Patient Portal Use Among Emergency Department Patients: An Open Results Study. *Appl Clin Inform*. Oct 2022;13(5):1123-1130. doi:10.1055/a-1951-3268

112. Trivedi N, Patel V, Johnson C, Chou WS. Barriers to accessing online medical records in the United States. *Am J Manag Care*. Jan 2021;27(1):33-40. doi:10.37765/ajmc.2021.88575

113. Pillemer F, Price RA, Paone S, et al. Direct Release of Test Results to Patients Increases Patient

Engagement and Utilization of Care. *PLoS One*. 2016;11(6):e0154743. doi:10.1371/journal.pone.0154743

114. Hu X, Qu H, Houser SH, et al. Exploring association between certified EHRs adoption and patient experience in U.S. psychiatric hospitals. *PLOS ONE*. 2020;15(6):e0234607. doi:10.1371/journal.pone.0234607

115. Schleiden LJ, Odukoya OK, Chui MA. Older Adults' Perceptions of E-Prescribing: Impact on Patient Care. *Perspect Health Inf Manag*. 2015;12(Winter):1d.

116. Crampton NH, Reis S, Shachak A. Computers in the clinical encounter: a scoping review and thematic analysis. *J Am Med Inform Assoc*. May 2016;23(3):654-65. doi:10.1093/jamia/ocv178

117. Banguilan KL, Sonnenberg F, Chen C. Physicians' Perspectives on Inpatient Portals: Systematic Review. *Interact J Med Res*. Nov 15 2022;11(2):e39542. doi:10.2196/39542

118. Girault A, Ferrua M, Fourcade A, et al. Current use and attitudes toward the use of information technologies in health care among cancer patients. *Journal of Clinical Oncology*. 2014;32(15_suppl):e20652-e20652. doi:10.1200/jco.2014.32.15_suppl.e20652

119. Yang Y, Asan O. Designing Patient-facing Health Information Technologies for the Outpatient Settings: A Literature Review. *J Innov Health Inform*. Apr 6 2016;23(1):185. doi:10.14236/jhi.v23i1.185

120. Walker E, McMahan R, Barnes D, Katen M, Lamas D, Sudore R. Advance Care Planning Documentation Practices and Accessibility in the Electronic Health Record: Implications for Patient Safety. *Journal of Pain and Symptom Management*. 2018;55(2):256-264. doi:10.1016/j.jpainsymman.2017.09.018

121. Bredfeldt C. PS2-10: Economic Impact of Electronic Health Information Exchange. *Clinical medicine & research*. 09/01 2013;11:152. doi:10.3121/cmr.2013.1176.ps2-10

122. Carr CM, Gilman CS, Krywko DM, Moore HE, Walker BJ, Saef SH. Observational Study and Estimate of Cost Savings from Use of a Health Information Exchange in an Academic Emergency Department. *Journal of Emergency Medicine*. 2014;46(2):250-256. doi:10.1016/j.jemermed.2013.05.068

123. Pitts SI, Maruthur NM, Wang X, et al. Team-Based Health Information Exchange Use Increased Mammography Documentation and Referral in an Academic Primary Care Practice: An Interrupted Time Series. *Journal of General Internal Medicine*. 2018/05/01 2018;33(5):710-714. doi:10.1007/s11606-017-4259-8

124. Rudin RS, Motala A, Goldzweig CL, Shekelle PG. Usage and Effect of Health Information Exchange. *Annals of Internal Medicine*. 2014/12/02 2014;161(11):803-811. doi:10.7326/M14-0877

125. De Leon SF, Pauls L, Arya V, Shih SC, Singer J, Wang JJ. Effect of Physician Participation in a Multi-element Health Information and Data Exchange Program on Chronic Illness Medication Adherence. *J Am Board Fam Med*. Nov-Dec 2015;28(6):742-9. doi:10.3122/jabfm.2015.06.150010

126. Byrne CM, Mercincavage LM, Bouhaddou O, et al. The Department of Veterans Affairs' (VA) implementation of the Virtual Lifetime Electronic Record (VLER): findings and lessons learned from Health Information Exchange at 12 sites. *Int J Med Inform*. Aug 2014;83(8):537-47.

doi:10.1016/j.ijmedinf.2014.04.005

127. Ruley M, Walker V, Studeny J, Coustasse A. The Nationwide Health Information Network: The Case of the Expansion of Health Information Exchanges in the United States. *The Health Care Manager*. 2018;37(4)

128. Valle J, Gomes C, Godby T, Coustasse A. The Feasibility of the Nationwide Health Information Network. *Health Care Manag (Frederick)*. Apr-Jun 2016;35(2):103-12. doi:10.1097/hcm.0000000000000101

129. Devine EB, Totten AM, Gorman P, et al. Health Information Exchange Use (1990-2015): A Systematic Review. *EGEMS (Wash DC)*. Dec 7 2017;5(1):27. doi:10.5334/egems.249

130. Adler-Milstein J, Lin SC, Jha AK. The Number Of Health Information Exchange Efforts Is Declining, Leaving The Viability Of Broad Clinical Data Exchange Uncertain. *Health Aff (Millwood)*. Jul 1 2016;35(7):1278-85. doi:10.1377/hlthaff.2015.1439

131. Elysee G, Herrin J, Horwitz LI. An observational study of the relationship between meaningful use-based electronic health information exchange, interoperability, and medication reconciliation capabilities. *Medicine*. 2017;96(41)

132. Downing NL, Adler-Milstein J, Palma JP, et al. Health information exchange policies of 11 diverse health systems and the associated impact on volume of exchange. *J Am Med Inform Assoc*. Jan 2017;24(1):113-122. doi:10.1093/jamia/ocw063

133. Adler-Milstein J, Jha AK. Health information exchange among U.S. hospitals: who's in, who's out, and why? *Healthcare*. 2014/03/01/ 2014;2(1):26-32. doi:https://doi.org/10.1016/j.hjdsi.2013.12.005

134. Bailey JE, Wan JY, Mabry LM, et al. Does Health Information Exchange Reduce Unnecessary Neuroimaging and Improve Quality of Headache Care in the Emergency Department? *Journal of General Internal Medicine*. 2013/02/01 2013;28(2):176-183. doi:10.1007/s11606-012-2092-7

135. Lee S-Y, Cherian R, Ly I, Horton C, Salley AL, Sarkar U. Designing and Implementing an Electronic Patient Registry to Improve Warfarin Monitoring in the Ambulatory Setting. *The Joint Commission Journal on Quality and Patient Safety*. 2017/07/01/ 2017;43(7):353-360. doi:https://doi.org/10.1016/j.jcjq.2017.03.006

136. Klompas M, Eggleston E, McVetta J, Lazarus R, Li L, Platt R. Automated detection and classification of type 1 versus type 2 diabetes using electronic health record data. *Diabetes Care*. Apr 2013;36(4):914-21. doi:10.2337/dc12-0964

137. Bradley PS. Implications of Big Data Analytics on Population Health Management. *Big Data*. 2013/09/01 2013;1(3):152-159. doi:10.1089/big.2013.0019

138. Banerjee D, Thompson C, Bingham A, Kell C, Duhon J, Grossman H. An Electronic Medical Record Report Improves Identification of Hospitalized Patients With Heart Failure. *J Card Fail*. May 2016;22(5):402-5. doi:10.1016/j.cardfail.2015.12.006

139. Williams KS, Shah GH, Leider JP, Gupta A. Overcoming Barriers to Experience Benefits: A Qualitative Analysis of Electronic Health Records and Health Information Exchange Implementation in Local Health Departments. *EGEMS (Wash DC)*. Sep 4 2017;5(1):18. doi:10.5334/egems.216

140. Feng C, Le D, McCoy AB. Using Electronic Health Records to Identify Adverse Drug Events in

Ambulatory Care: A Systematic Review. *Appl Clin Inform*. 2019/02/20 2019;10(01):123-128. doi:10.1055/s-0039-1677738

141. Walker DM, Yeager VA, Lawrence J, McAlearney AS. Identifying Opportunities to Strengthen the Public Health Informatics Infrastructure: Exploring Hospitals' Challenges with Data Exchange. *Milbank Q*. Jun 2021;99(2):393-425. doi:10.1111/1468-0009.12511

142. Anderson D, Zlateva I, Khatri K, Ciaburri N. Using health information technology to improve adherence to opioid prescribing guidelines in primary care. *Clin J Pain*. Jun 2015;31(6):573-9. doi:10.1097/ajp.0000000000000177

143. Bower JK, Patel S, Rudy JE, Felix AS. Addressing Bias in Electronic Health Record-based Surveillance of Cardiovascular Disease Risk: Finding the Signal Through the Noise. *Current Epidemiology Reports*. 2017/12/01 2017;4(4):346-352. doi:10.1007/s40471-017-0130-z

144. Chen L, Shortreed SM, Easterling T, et al. Identifying hypertension in pregnancy using electronic medical records: The importance of blood pressure values. *Pregnancy Hypertension*. 2020/01/01/ 2020;19:112-118. doi:https://doi.org/10.1016/j.preghy.2020.01.001

145. Dixon BE, Holmes JH, Section Editors for the IYSoMPwHI. Managing Pandemics with Health Informatics. *Yearb Med Inform*. Aug 2021;30(1):69-74. doi:10.1055/s-0041-1726504

146. Dixon BE, Jones JF, Grannis SJ. Infection preventionists' awareness of and engagement in health information exchange to improve public health surveillance. *American Journal of Infection Control*. 2013;41(9):787-792. doi:10.1016/j.ajic.2012.10.022

147. Dhakal S, Burrer SL, Winston CA, Dey A, Ajani U, Groseclose SL. Coding of Electronic Laboratory Reports for Biosurveillance, Selected United States Hospitals, 2011. *Online J Public Health Inform*. 2015;7(2):e220. doi:10.5210/ojphi.v7i2.5859

148. Cook L, Espinoza J, Weiskopf NG, et al. Issues With Variability in Electronic Health Record Data About Race and Ethnicity: Descriptive Analysis of the National COVID Cohort Collaborative Data Enclave. *JMIR Med Inform*. 2022/9/6 2022;10(9):e39235. doi:10.2196/39235

149. Shah GH, Leider JP, Luo H, Kaur R. Interoperability of Information Systems Managed and Used by the Local Health Departments. *J Public Health Manag Pract*. Nov-Dec 2016;22 Suppl 6, Public Health Informatics(Suppl 6):S34-s43. doi:10.1097/phh.0000000000000436