



HL7 EHR Guidance: Reducing Clinician Burden,
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**Health Informatics—Technical Report on Pathways for Human
Computer Interaction in Electronic Health Information Record
Systems to Reduce Clinician Burden**

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Overview

The implementation of electronic Health Information Record Systems (HIRS) is one of the primary factors contributing to a sustained and significant negative impact on clinical practice and patient experience. The term Health Information Record System is defined by Health Level Seven (HL7®) International as a data definition language which allows formal definition information structures to be expressed in a manner which is independent of any implementation constraints. HIRS may be used to create complex hierarchical structures from basic primitive types. HIRS has substantially altered the norms of clinician-patient interaction; often unintentionally diminishing the most meaningful aspects of healthcare practice for the clinician and the patient. [1], [2], [3], [4], [5]. Among the various segments of the healthcare industry, there is widespread agreement that the structure, capabilities and operations within HIRS are not working for clinicians, patients, health organizations, health technology vendors or the businesses who enable the provision of health insurance, equipment, biotechnology services, research, and pharmaceuticals. The healthcare industry faces a diverse range of challenges causing numerous serious issues for each of these groups. Challenges include rising numbers of preventable mistakes [6], declining quality of care, sub-optimal health outcomes, out-of-control costs, financial pressure, resource constraints, clinician burnout, and problems integrating technology with Artificial Intelligence (AI) and telehealth. These ever-changing technical, regulatory, and environmental challenges, along with cybersecurity threats to patient data requiring robust security measures and constant vigilance, demand significant additional effort, planning and resources. These challenges impact operational efficiency and can lead to workforce shortages. There is a growing gap in the availability of skilled healthcare professionals and healthcare services relative to growing demand for healthcare services as populations age and the prevalence of chronic diseases rises.

The root cause(s) of many of these challenges relate to deeper issues with HIRS including:

Inadequate standards for data quality and insufficient auditing and enforcement of existing data quality standards.

Complex nonintuitive data structures and functionalities

Lack of functionalities to mitigate cognitive overload

Fragmented care, poor workflow integration and lack of context and specialty specific support [7]

While the problems are daunting, the problems appear to have motivated many healthcare and non-healthcare ‘actors’ to start to identify solutions. This TR reviews a large body of clinician opinion and research findings suggesting that the HIRS status quo cannot continue and that comprehensive HIRS reform is necessary, possibly leading to a completely new HIRS which would be termed the Digital Health System (DHS). During the transition to a new HIRS, clinicians must continue to treat patients with the available HIRS; the idea of moving to a more perfect DHS is an evolutionary process over a period of years. The goal now is to use the knowledge, principles, standards and experience gained from the first 15 years of wide scale HIRS implementation, and the advances made in several domains to support continuing efforts to improve HIRS and move toward that more perfect DHS.

While the burden of disease is a known epidemiologic concept, clinician burden is a less known and more recent term [8]. Clinician burden occurs when the clinician’s environment and workload impose physical, cognitive, psychological, and time burdens on clinicians without sufficiently improving quality of care and clinician functioning [2]. Multiple factors can contribute to clinician

burden, including 1) time and productivity pressures, 2) excessive bureaucratic tasks of low clinical value, 3) limited capacities of human cognition versus high demands of information-intensive clinical practice [9], [10], and 4) lack of effective HIRS functionalities and clinical decision support tools to assist clinicians.

While contributing to improved healthcare, the volume and velocity of new patient-related healthcare information, patient-specific data, and underlying biomedical knowledge also unintentionally increase clinician burden [11]. A large and growing body of research suggests that poor HIRS usability and poor integration within clinician workflows are important factors preventing electronic health information record systems from achieving the clinician accuracy and productivity crucial for safer patient healthcare outcomes [12]. The human-factor design and clinician workflow burdens imposed on clinicians by current HIRS have contributed to an epidemic of clinician burnout. This interplay of factors has contributed to clinician shortages, patient dissatisfaction from rising wait times, preventable medical errors, declining health outcomes and rising healthcare costs. [3], [13],[14],[15],[16],[17].

A comprehensive international strategy to reduce clinician burden related to HIRS should focus on improving Human-Computer Interaction (HCI) as a fundamental principle. In 2022, the Health Level Seven International (HL7®) Reducing Clinician Burden Project (RCB) completed an environmental scan of clinician burdens associated with HIRS documentation and clinician workflows [18]. The HL7® scan detected two underlying categories of clinician burden: 1. Inefficient interactions with HIRS technology itself and 2. Excessive additional requirements for administrative, regulatory, and organizational tasks imposed and managed via the HIRS. In this context, digital tools can be neutral, positive or negative. Digital tools are neutral when the tools are effectively implementing an imposed task. The tools can be negative, adding to clinician burden, when digital tools are poorly designed or poorly implemented. The tools can be positive when intelligent design enables the tools to alleviate existing burden e.g., by reducing cognitive load or automating regulatory compliance.

Prior studies of the length of progress notes [5] and of Electronic Health Record (EHR) usage patterns [19] around the world suggest that documentation and other EHR-related burdens may differ between the United States (US) and other international healthcare systems, possibly due to unique healthcare regulatory and payment models in the US. It also seems clear that the motivation and incentives for adoption and implementation of EHRs in the international arena arise from different backgrounds and histories. Given these differences, it is not clear whether the levels and causes of clinician burden and burnout around the world would be similar to those seen in the US. However, conversations with informatics professionals [Personal Communications, 2023-5] as well as other studies in the literature [20], [21], [22], [23], [24] suggest there may be more similarities than differences. In order to better define clinician burdens related to healthcare information technology (health IT) and prepare for writing international standards that could reduce those burdens, the ISO TC 215/HL7 International Joint Reducing Clinician Burden Project (JRCB) developed and distributed a survey to examine the level of clinician burnout in the international arena and determine whether such burnout is related to the implementation and use of health IT. [25]

The survey received 180 discrete responses from 21 countries (and one from the US), mainly from healthcare clinicians, informaticians, and administrators. The overwhelming majority of respondents (92%) rated the level of clinician burnout in their countries as moderate or severe. Most respondents also reported that EHR-related burden was substantial and that burden in their countries was not different from that in the US (62%). Eighty-nine percent of respondents felt that health-IT related

burden was a significant contributor to burnout. The majority of countries reported that primary care clinicians and specialists used different EHRs (77%), and 88% of respondents felt that this contributed to burden in their countries. Although a majority of respondents (56%) indicated their countries had implemented some type of standards for EHR development, most (>60%) felt such standards were insufficient and frequently bypassed. A significant majority (75%) also reported that standards specifically related to clinician burden were not being developed in their countries.

The results of the survey suggest that clinician burden and burnout are prevalent in multiple areas of the world and represent an international concern regardless of local regulatory systems and payment models. They also suggest that EHRs and other aspects of health IT are significant contributors to the problem. An international standards-based approach that creates incentives for vendors to transparently include best practices of user-centered design and human computer interaction in their health IT development processes can help stimulate the development of more effective, efficient, satisfying [26] digital tools that alleviate clinician burden and enable better quality care.

Health Informatics—Technical Report on Pathways for Human Computer Interaction in Electronic Health Information Record Systems to Reduce Clinician Burden

1. Scope

This document describes the need for standardization of Human-Computer Interaction (HCI) design of electronic health information record systems (HIRS). The focus is the application of HCI to HIRS data analytics and clinical decision support to alleviate HIRS-associated clinician burden. The TR introduces HCI-based design as a core method to optimize HIRS ability to improve the clinician experience and thereby reduce clinician burden and accelerate clinician decision-making for optimal healthcare outcomes. The TR lays the foundation for future work on developing standards to mitigate the causes of clinician burden.

2. Informative references

The following documents are informative to the HCI-HIRS Technical Report in all or some of the referenced document content. The current edition of the document applies.

- ISO 13606-3:2019 *Health informatics — Electronic health record communication Part 3: Reference archetypes and term lists*
- ISO 18104:2023 *Health informatics — Categorial structures for representation of nursing practice in terminological systems*
- Health Level Seven (HL7®) International, Inc. Electronic Health Record Systems — Functional Model (EHRS-FM) Release R2.0.1: Usability Functional Profile, Release 1

3. Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- ISO/TC215 Standard Knowledge Management Tool (SKMT) browsing platform: available at www.skmtglossary.org
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

Burden

measure of extra effort imposed by the healthcare information environment when the clinician attempts to access, interpret, record, or distribute information.

3.2

Clinician

professional involved in the delivery of healthcare services to a person.

3.3

Clinical decision support

system designed to assist clinicians with clinical decision-making tasks for health improvement.

3.4

Health decision support

system designed to empower individuals to make informed health decisions in daily lives. CDS and HDS systems have complementary roles in improving overall health outcomes.

3.5

Clinician burden

effect of the clinician's environment and workload on patient treatment and outcome.

3.6

Digital health

systems, tools, and services based on information and communications technology used to enhance the efficiency of healthcare delivery, make medicine more personalized and precise, and improve health outcomes through digital tools and platforms.

3.7

Electronic health record

digital information system used by clinicians to create, update, import, store, and exchange clinical information for patient care.

3.8

Electronic health information record system

body of computer-processable health information, stored securely, and accessible by authorized users.

3.9

Healthcare data

aggregated data produced in the course of healthcare activities.

3.10

Healthcare datum

individual datum produced in the course of healthcare activities.

3.11

Healthcare service

service provided with the intention of directly or indirectly improving the health of the person or populations to whom care is provided.

3.12

Human-computer interaction

discipline concerned with the design, evaluation, and implementation of interactive computing systems for human use and with the study of major phenomena surrounding the interaction between humans and computers.

3.13

Human factors

scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and profession that applies theory, principles, data, and methods to design in

order to optimize human well-being and overall system performance.

3.14

Interface

process that permits the flow of data from one system to another in a structured manner.

3.15

Information technology

assembly of computer hardware, software and/or firmware configured to collect, create, communicate, disseminate, process, store and/or control data or information.

3.16

Interoperability

ability of a system to exchange electronic health information with and use electronic health information from other systems without special effort on the part of the user.

3.17

Natural language processing

a subfield of artificial intelligence and linguistics which studies the problems inherent in the processing and manipulation of natural languages, and natural language understanding devoted to making computers 'understand' statements written in human languages.

3.18

Remote patient monitoring

approach using technology to monitor patients outside of traditional clinical settings, such as in the home, for clinicians to track and measure the output of digital medical devices such as blood pressure monitors, pulse oximeters, blood glucose meters, cardiac rhythms. The data collected from devices are electronically transferred to clinicians for care management. [27]

3.19

Wearable devices

portable medical or health electronic devices worn directly on the body to observe, record, analyze, regulate, and intervene to maintain health or treat diseases with the support of technology. [28]
This data collected from wearable devices may be electronically transferred to clinicians and others on a patient's health team for care management.

3.20

Workflow

a sequence of actions carried out to achieve complex objective(s).

4. Abbreviated terms

AI	Artificial Intelligence
BCMA	Barcode Medication Administration
CDS	Clinical Decision Support
C/HDS	Clinician/Health Decision Support
CMS	Centers for Medicare and Medicaid Services (CMS)
DAI	Drug Allergy Interactions
DDI	Drug-Drug Interactions

DHS	Digital Health Systems
EHR	Electronic Health Record System
GDP	Gross Domestic Product
HCI	Human-Computer Interaction
HIRS	Electronic Health Information Record System
HL7®	Health Level Seven International SDO
ML	Machine Learning
NLP	Natural Language Processing
POHR	Problem Oriented Health Record
RPM	Remote Patient Monitoring
SDO	Standard Development Organization
UX	User Experience
WIMP	Windows, Icons, Menus, Pointers

5. Clinician burden

Clinician burden due to inherent limitations of human cognitive function [9], [10] existed well before the advent of HIRS. Human beings are incredibly complicated. In addition to complex patterns of comorbidities, patients differ significantly in ethnic, genetic, physiological, molecular, and socioeconomic characteristics, in response to drugs and treatments, and in personal values and preferences. The biomedical science knowledgebase doubles 2 - 3 times each year with concern about the availability and accessibility of important data affecting new lines of scientific reasoning. Eliciting complete patient data, synthesizing the patient data into a coherent narrative, and coupling the narrative to an exploding knowledge base to accurately diagnose and treat disease is often a superhuman task [9], [10]. Clinicians routinely complete the tasks of data location and/or recall, data vetting and synthesis, and clinical decision making, often within the bounds of a 20-minute encounter, and are increasingly aware important data could be unavailable.

HIRS were intended to assume part of this cognitive load, improve workflow efficiency, and reduce clinician burden leading to more timely and accurate decision-making and improved care, health outcomes, and cost outcomes. However, HIRS were designed based on the principles and paradigms of healthcare in the late 20th century, in the HIRS era of the 1970's and 80's, without sufficient attention to HCI design and workflow integration. This resulted in HIRS products that many clinicians find inefficient, confusing, and difficult to use [29], [30]. The HIRS products of the 21st century have also been used as a mechanism to add many additional duties of significantly lower clinical value to the average clinician's workday. In sum, HIRS in the second decade of the 21st century often add to rather than alleviate clinician burden. So HIRS have failed to achieve an appropriate balance between clinicians, patients, and technology and have paved a destructive path to widespread clinician burnout, heightened healthcare dissatisfaction, increased safety risks and failure to slow the rise in healthcare cost [3], [13], [14], [31]. The HIRS promises to enable better quality patient care, better health outcomes, better patient experience, and reduced per capita costs remain unrealized.

According to a US National Health Data Brief, as of 2017, 94% of hospitals used HIRS data to perform hospital processes to inform clinical practice. In addition to patient care, data is commonly used to support quality improvement (82%), monitor patient safety (81 %), and measure

organization performance (77%). Hospital characteristics significantly impact the use of HIRS data with small, rural, and non-teaching hospitals having the lowest rates of using data [32]. Although, as of 2021, electronic HIRS were used in more than 95% of hospitals and nearly 80% of physician offices [33], studies have shown:

- No significant change in hospital length of stay or inpatient mortality [34], [35].
- No significant change in 30-day readmission rates or patient safety incidents [34], [35].
- No improvement in life expectancy, infant mortality, or other population health metrics [36], [37], [38].
- Continued rapid rise in annual healthcare expenditures from \$2 trillion in 2009 to over \$4.5 trillion in 2022 (nearly 18% of GDP) [39] with annual healthcare expenditures in the United States projected to have risen 7.5% in 2023 to \$4.8 trillion [40], outpacing the projected annual gross domestic product growth rate of 2.5% [41].
- Decreased efficiency in healthcare delivery with information systems adding 1-2 hours to the average physician workday) [42], [43].
- Disruption of physician work-life balance associated with an epidemic of clinician burnout [13], [14].
- Modest improvement in care process metrics and guideline adherence only weakly correlated with system use [44], [45], [46] [47].

5.1 Health information record systems

From another perspective, the wide-scale implementation of HIRS has imposed additional physical and cognitive workload and additional time requirements (i.e., burden) on professionals whose practice is based on the direct provision of healthcare services to patients (i.e., clinicians). The term “clinical workflow” encompasses all clinician physical and mental activities, technologies, tools, environments, teams, and organizations involved in patient care [48]. As such, clinical workflows are sequences of physical and cognitive actions, occurring over time and through space, which are performed by clinicians, which recall, vet, consume, transform, and/or produce information, and which are used to assess, maintain, or change the health of a patient.

The time consumed by the multiple technical inefficiencies related to ineffective HIRS design and functionalities along with regulation-induced documentation burdens disrupt work-life balance, thus being a major contributor to the current epidemic of physician burnout seen in the U.S [3], [5], [13], [49]. By definition, clinician burnout is a syndrome emerging as a prolonged response to chronic interpersonal and intrapersonal job stressors characterized by feelings of emotional exhaustion, cynicism and detachment from work, and a sense of low personal accomplishment [50]. About 50% of U.S. physicians report at least one symptom of burnout, twice the rate of the general population; and 70% of U.S. physicians report at least one symptom of health IT-related stress [13], [51]. A recent systematic review suggests a significant association between both burnout and depression and burnout and anxiety in physicians and an important relationship between burnout and suicidality [52], likely contributing to the increased rate of mental health issues and suicide seen in physicians compared to the general population [53]. A number of studies have also shown that the prevalence of clinician burnout correlates directly with usage of and frustration with electronic health records [3], [13], [16], [17].

5.2 Decision support systems / health modules

Data organized by source rather than clinical or health problem, complex user interfaces, and confusing navigation all render searching for, accessing, and organizing relevant information to locate complete information for a given problem within HIRS difficult and unnecessarily time consuming [54]. A lack of consistency from one HIRS system to another often further impedes clinician access to content. Other obstacles in the current generation of HIRS include mouse/keyboard interfaces, text-based documentation models, and complex paper-derived data representations. These require clinicians to “navigate deeply nested menus and browse through long pull-down lists that are neither filtered nor contextualized.” [55] Data is entered bit by bit requiring multiple keystrokes, points, clicks, and scrolls. This uses highly trained clinicians as data entry clerks. One study measured an average of 216 mouse clicks or wheels and 729 keyboard clicks per 20-minute patient visit [56]. A number of studies also indicate that increased time interacting with the computer is strongly associated with decreased patient satisfaction [14], [56], [57].

Information in HIRS is often not organized or aligned with the clinician’s mental model of care, making important information difficult to locate. Even at its best, the unaided human mind has difficulty coping with the massive volume and complexity of information needed to make optimal decisions, especially given that the total amount of biomedical knowledge doubles every 75 days [58], [59]. And human minds, affected by time pressure, other stressors, and limiting heuristics are being asked to do something that is humanly impossible. HIRS do not provide the tools needed to approach differential diagnosis in a complete and organized manner and properly couple the patient’s symptoms and findings to the underlying biomedical knowledge base [9], [60], [61].

In addition, that clinician’s mental model may not be optimized for clinical decision making. In either event, clicking, scrolling, switching between paths and screens, and counterintuitive data presentations make HIRS challenging to access and important data difficult to process [62], [54], [63], [64], [65]. Critical information is often obscured in a plethora of less important text or values [66]. Locating and importing data from outside a clinician’s health system requires extensive effort and such effort may not succeed [30] raising concerns the available information represents only a narrow and incomplete view of the patient. Nearly 60% of ambulatory care providers report being dissatisfied with their own electronic health record due to workflow and usability concerns [66], and about 70% of primary care physicians surveyed responded that HIRS contribute to physician burnout and HCI redesign is necessary to improve inefficiencies and reduce screen time [67].

Effective HIRS Clinical / Health Decision Support (C/HDS) provides the right information to the right person in the right clinical intervention format through the right channel at the right point in workflow [68] with well-designed HCI methods [63], [64]. Using artificial intelligence tools to properly process data already in the HIRS at a more sophisticated and granular level could be used to focus CDS outputs and refine CDS trigger levels to decrease the number of low value alerts [69]. Such an AI-enabled HIRS could also show the clinician the underlying data and rationale leading to an alert or recommendation, at a clinician-selectable level of detail, and allow the clinician to immediately act on the information. A properly interactive HIRS CDS system should allow clinicians

to provide system feedback on the accuracy and clinical utility of alerts to be used in iterative rounds of system optimization. In CDS systems, modules, tools should not have to be created as a ‘one-off’ unique or customized configurations in every new HIRS implementation. Global healthcare regulators should support the creation of internet accessible data repositories of validated, curated biomedical knowledge modules and basic operational components (triggers, notifications, etc.) available as standard sets and templates [70].

A systematic review of twenty-eight randomized trials of electronic health record decision support systems showed no survival benefit and minimal impact on morbidity [71]. As the medical and scientific knowledge base expands exponentially [58], [59], physicians and care teams need standardized tools to appropriately navigate, assimilate and apply information to complex healthcare interrelationships found among the patient narrative, physical exam, laboratory data, radiographic images, and care delivery. Current HIRS decision support interventions often present in the form of pop-up alerts notifying physicians and clinicians of warnings such as drug-drug interactions (DDI), drug allergy interactions (DAI), dose ranges etc. Other decision support formats include order sets with direct links to medical literature or links to guidelines, calculators, or knowledge summaries. Unfortunately, many DDI and DAI tools are interruptive and fail to integrate key pieces of data found throughout the HIRS, resulting in large numbers of low value alerts, leading to “alert fatigue.” The proportion of overridden DDI alerts range from 50% to 90% in various studies, with over 60% of the overrides found to be clinically appropriate [72]. Linked literature and knowledge summaries frequently display far more information than needed at the current point in workflow, requiring a long search to find the piece needed to complete the immediate clinical task [73].

In various settings, nurses spend anywhere from 22% to 33% of patient care time in medication related activities [74], [75]. Researchers have found current barcode medication administration (BCMA) systems can interfere with nurses’ problem-solving, ability to integrate medication administration with other care activities, and ability to collaborate and share workload [76], [77]. The lack of context specificity and standardization in care tools and terminology challenges the nurse to efficiently spot trends in data over time, effectively summarize data for communication across organizations or service lines, and accommodate variation in nursing knowledge and experience [78], [79].

Nursing documentation is crucial in the nursing process, for communicating with other care team members, for establishing comprehensive care plans, and for recognizing trends in patients’ needs and clinical condition. A recent study found that nearly a fifth of patient files contained inaccurate medication dose documentation, nearly a third showed one or more care orders was fulfilled late, and in nearly half, nursing patient documentation was partially missing [80]. Another study identified perioperative documentation, including perioperative nursing notes, as a source of communication failures among providers [81].

A recent study [17] administered the System Usability Scale (SUS), a validated metric of IT system usability [82] to over 8600 U.S. nurses who on average rated the usability of EHRs as ‘very poor’.

The same study also found poor SUS scores were significantly correlated with nurses' levels of burnout as assessed by the Maslach Burnout Inventory [83], [84]. The volume of HIRS data has increased cognitive workload and time requirements in practice. The National Academy of Medicine [31] described system factors preventing the optimization of direct patient care delivery as poor clinical data integration and poor data usability. Poor nursing data leads to a nursing information burden and accelerates a need for a semantically and syntactically aligned health ecosystem "without requiring extra input or 'special effort' [85]. A partnership of HIRS nursing practice documentation with structured, standardized, and coded HIRS nursing terminology would advance the interoperability and usefulness of nursing data.

5.3 Patient portals

Patient portals provide patients with a communication platform and method of insight into personal health conditions to help patients actively manage individual health, communicate with providers and carry out a number of administrative tasks such as scheduling appointments, paying bills and other actions. A 2015 systematic review of patient portals [86] showed significant improvements in patient self-management of chronic disease and improvement in the quality of care provided by providers. The most prevalent positive attribute was patient-provider communication, which appeared in 10 of 27 articles (37%). The most prevalent negative perceptions were security (concerns) and user-friendliness which occurred in 11 of 27 articles (41%).

In 2020 the acceleration of web-based patient-clinician interaction using patient portals was predicted to achieve high-quality, patient-centered care. Studies to understand the healthcare professionals' experiences of web-based, patient-professional communication via patient portals find clinicians experience positive as well as negative reactions to such communications [87]. "Most commonly, the positive experiences seem to be related to patient satisfaction and outcomes, such as having better patient engagement. Healthcare professionals also report some negative experiences with portal-based communication, for example, operational deficiencies and a negative impact on clinician workload. The negative experiences may be due to "the poor functionality of patient portals and insufficient training or resources". The sheer volume of patient messages received from patient portals requiring clinician responses are another factor creating additional clinician burden that did not exist prior to HIRS and patient portals.

5.4 Remote patient monitoring (RPM) / wearable devices

In addition to transmitting high volumes of patient questions and communications, HIRS have also enabled an explosion of inbound quantitative data via the ability to interface with RPM devices. The accuracy of the data collected by RPM devices is a clinician concern. Inaccurate data can lead to incorrect diagnoses or treatment plans [88]. Patients may struggle with using the technology correctly or consistently, which can affect the reliability of the monitoring [89]. Integrating RPM data with existing HIRS and other healthcare systems can be complex and time-consuming, and the cost of RPM devices and the infrastructure needed to support may be a barrier for some healthcare

providers and patients [88], [89]. As RPM mediates direct care delivery, clinicians face an increased workload due to the constant influx of data to be monitored and analyzed [90].

Remote patient monitoring (RPM) requires robust data management practices and security protocols to protect sensitive health information [88]. Also required for effective use is digital literacy for both patients and healthcare providers. [91]. Some RPM devices provide continuous monitoring. This and other RPM activities outside of scheduled clinical practice hours contribute to clinician burden in documentation. The volume of information gathered and recorded by portals and RPM devices far exceeds the ability of clinicians to analyze and respond to the data in real time. Such systems must be required by certification standards to process, analyze and sort incoming data, recognize urgent situations or trends, escalate to human clinicians for immediate action with priority communications queued for human review.

5.5 Ontology-based systems

Managing and maintaining ontologies can be complex due to the need for continuous updates and alignment with evolving medical knowledge and standards [92]. In order to address these challenges, the underlying data, vocabulary, language and ontology architectures must be flexible, modular and granular. Many healthcare systems still use older technologies that may be incompatible with modern ontologies. Integrating the ontology systems requires significant effort and resources [92]. Data from different digital healthcare systems, e.g., HIRS, RPMs, laboratory and imaging devices, is heterogeneous in structure and format and therefore challenging to standardize and integrate into ontology-based systems [93]. This impedes the use of such systems in speeding information retrieval to reduce clinician burden. In addition, there is often a shortage of professionals with the expertise to develop, implement, and maintain ontology-based systems in healthcare [94]. Definitions of each data element and semantic interoperability are crucial so that different systems can understand and use the same data consistently. Finally, the challenge of aligning the diverse specialized coding and classification systems used in healthcare must be addressed in order for ontology-based systems to succeed [95].

5.6 Knowledge repositories

Using knowledge repositories in healthcare can present several challenges contributing to clinician burden including data security and privacy. The Health Insurance Portability and Accountability Act of 1996 (HIPAA) requires stringent standards for the electronic exchange, privacy and security of protected health information yet permits health information exchange as needed to provide and promote high quality health care and advance public health. In the United States, interpreting HIPAA regulations and implementing compliant information systems can be complex and costly [96].

As healthcare data comes from various sources (e.g., various HIRS, laboratories, and imaging centers) integrating the veracity of data into a single knowledge repository while maintaining privacy, accuracy and provenance can be technically challenging and time-consuming [97]. As with

ontologies, inconsistent data formats and quality can impede standardization and decrease knowledge repositories' usefulness for clinical information retrieval [98]. In addition, maintaining and updating knowledge repositories requires significant investment and identifying a sustainable funding model for a knowledge repository is often a significant organizational challenge [97]. Because each knowledge nub is coded and time/date stamped, the piece can be used in real time in AI-analytical engines to provide guidance on each patient's acute or chronic concern with transparency on the pedigree and provenance of the clinical data and guidance. The scaling of the knowledge repositories and continuous update are important challenges to address.

6. Burden mitigation

Clinician burden mitigation aims to reduce the avoidable components of the stress experienced by clinicians. There are several approaches to reduce paperwork and administrative duties, redesigning clinical processes and workflows to minimize unnecessary steps, optimize the use of time and resources; and ensure clinicians have sufficient staff and resources to handle non-clinical tasks. Several organizations focus on enhancing clinician work-life balance by offering flexible work schedules, mental health support, and wellness programs to assist in stress management to avoid clinician burnout. While such programs are valuable, as a single modality they are not sufficient to mitigate the majority of clinician burden.

In reducing clinician burden, robust data-driven HCI design and development standards for healthcare could significantly alleviate clinician burden through several key mechanisms to improve the usability of HIRS. Enhancing usability can streamline clinical workflows and reduce the time clinicians spend on documentation. This can be achieved by improved, more specialty specific interface designs and by organizing data by clinical problem rather than by the provider of the data or the method used to generate the data. A great deal can be done by shielding clinicians from the technical aspects of information processing by reducing the administrative HIRS burden and streamlining clinician processes to focus on patient care. Examples of such mechanisms include:

- New electronic systems that, especially if supported by rapidly developing AI methodology, can guide patients and skilled non-clinician members of the patient's care team to perform data entry and vetting, and provide guidance regarding medication history documentation rather than clinicians. [99] These trained 'health assistants' include patients, patient surrogates, health coaches, health coordinators, community health workers and social workers. Such new supplemental care team members can ease data entry burden, providing a significant force multiplier at a time when clinicians' workload is ballooning and perhaps contributing to the shortage of clinicians.
- Automation of Routine Non-Clinical Tasks: AI and ML can potentially automate many routine administrative tasks such as scheduling, billing, and coding. This reduces the workload on clinicians, allowing more focus on patient care. [99]

- **Lean Clinical / Health Decision Support (C/HDS):** Offer evidence-based recommendations and alerts to support informed decision-making and reduce cognitive load. It is vital that such C/HDS be designed to provide precisely the information, guidance, and the source of the guidance needed at the current point in a workflow, so the C/HDS does not itself become a source of overload. C/HDS connection to both Knowledge Repositories and the patient's POHR could enable the use of newly developing AI systems (e.g., analytics engines or large language models) to couple the two knowledge bases to derive optimized data-driven guidance for each of the patient's clinical problems, and these activities can be initiated without clinician involvement [99] [100], [101].
- **Voice Recognition and Natural Language Processing (NLP):** Technologies such as voice recognition, NLP, and ambient listening systems can assist in transcribing clinical notes, navigating the HIRS, and generating documentation, saving time and reducing the risk of errors. [102]
- **Telemedicine and Remote Patient Monitoring (RPM):** HCI design principles in telecommunication systems enhance the usability, accessibility, and effectiveness of telemedicine and RPM systems, which can reduce the need for in-person visits and allow clinicians to appropriately manage the incoming tidal wave of data from portals and RPM devices. [103], [104]
- **Enhanced Patient Engagement Tools:** Interactive patient portals, mobile health apps, RPM and wearable devices, and symptom checkers allow patients to better understand their own illnesses, manage personal health and engage in healthy behaviors, which has the potential to decrease the frequency of visits and the burden on healthcare delivery system.

6.1 Human-computer interaction

“The primary purpose of clinician documentation should be to support patient care and improve clinical outcomes through enhanced communication” [105]. Selecting which data to present at a particular point in care and organizing the data so that the clinician's thinking is easily consumed and understood by the rest of the care team is a complex, variable, context-dependent process. This process must be context-aware, must capture variability reflecting patient uniqueness, and must avoid variability reflecting provider idiosyncrasies. Only in that way can the process be centered on patients rather than providers. Problem Oriented Health Record (POHR) advocates believe that such a patient-centered process is built into the design and use of the problem-specific data collection questionnaires described above.

Commitment to patient-centered care requires clinicians to confront individual patient variability as clinicians diagnose and treat each patient resulting in highly variable workflows and many unarticulated, sometimes unconscious thought processes, which are more likely to be

individualized than shared by most clinicians. No matter whom a HIRS product elects to emulate, the HIRS product being developed inevitably is based on the experiences, interactions, and constraints of a relatively small number of clinicians [106], and the results may not reflect the needs of the wider clinician community. HCI design at a more granular, specialty-specific level can mitigate the problem by supporting development of more context aware, specialty specific HIRS [107].

The idea that healthcare should be patient-centered is one of the foundational tenets of the healthcare system. Similarly, from the earliest steps on the pathway to becoming healthcare professionals, clinicians become deeply committed to a foundational moral principle: the needs of the patient come first. Recently, the daily experience of clinical practice has been increasingly affected by insufficient resources, demands for system performance improvement, production pressures, and changes in reimbursement structures [49]. Under hazard to individual careers, clinicians face strong pressure to consider the needs of the HIRS, the payers (public and private), associated healthcare organizations, and government regulators as potentially equivalent to patient needs [108].

Current HCI design and implementation paradigms are based on principles derived from prior research and historical precedents. On this basis, HCI often relies on the assumption there is one ideal clinician workflow to carry out and document a given clinical process which is valid and optimal in all contexts. This assumption has never been validated and appears to encourage the suppression of clinician and clinical practice variability even though variability in clinical practice is nearly inevitable. In failing to adequately account for cognitive psychology and human factors, the HCI design in current HIRS products creates many impediments to the clinician workflow.

In general, clinicians seek to enable workflow variability and individualization by patient while, at the same time, standardize approaches having to do with data quality, data organization, delivery, transparency of guidance options, and ethical concerns. Clinicians also seek to standardize the use of knowledge repositories attached to AI-engines in order to deliver patient specific guidance options, with references, to document the pedigree and provenance of the data and resulting guidance option. There can be greater standardization surrounding the automation of data collection, refinement, analysis, guidance options and documentation preparation. Clinicians should have access to each patient's HIRS POHR instead of putting together a clinician's POHR for each patient. Providing patient centric flexibility and adaptability, HIRS systems need granular, flexible, modular data dictionaries, languages, ontologies and architectures [93].

In general, the current generation HIRS HCI design applies a rationalized model of healthcare represented as algorithmic sequences of care delivery choices. Clinician care is iterative and rarely linear. Physicians and nurses continuously reformulate goals, revise tasks or interventions, and reorder sequences of care as new patient information is acquired through interaction with individual patients, colleagues and by encountering clinical constraints [29]. Physician workflows are inherently complex, nonlinear, and dependent on a wide variety of data inputs. Physician

workflows differ significantly between specialties, between individual providers, between clinical scenarios, diagnoses, and locations, and even between individual patients for a single physician.

For example, one detailed study of two patient visits by ten Primary Care Providers (PCPs) in ten different primary care centers observed no single, or even common, workflow pattern. The order and prevalence of task categories varied through the time course of a visit, with the PCPs collecting data throughout the visit [109]. Another study of 55 emergency department physicians at four sites using two different HIRS products showed wide variability in task durations, treatment ordering, HIRS navigation screen selections (clicks), and accuracy when completing basic functions across HIRS products from the same vendor and between products from different vendors [110].

Requiring clinicians to allot ever increasing amounts of time for HIRS training to modify clinician processes and workflows to conform to pre-configured systems with suboptimal HCI does not appear to improve the quality of healthcare or decrease clinician burden or burnout. Rather, improving HCI requires new flexible, modular HIRS systems which can adapt to variable patient problem situations and provide better CDS tools to reduce cognitive burden. Disruptive innovation and real progress will require HIRS to evolve from data-centric transactional systems or electronic filing cabinets to process and patient-centric workflow systems, designed from the ground up to be flexible and context-aware and to provide “just in time” delivery of exactly the data, knowledge and functionality the physician needs at the current point in workflow.

Exacerbated by inefficiencies related to the HIRS, the demands on clinicians have escalated exponentially without any corresponding increase in time with patients or resources. In a recent survey of over 1200 clinicians, 75% agreed or strongly agreed with the statement, “The effort or time required for me to complete documentation tasks impedes patient care.” [111] To meet the demands and satisfy intrinsic requirements and standards of providing the best possible care, clinicians devote lunch hours, evenings, and weekends to completing documentation. If most doctors and nurses signed out and stopped work at the end of the shifts, the healthcare system would collapse [112]. Despite best efforts, clinicians often cannot escape the double bind of knowing what the patient needs and awareness of being unable to meet the need due to circumstances beyond their control, a phenomenon termed “moral injury.” [108]

6.2 HCI benefits

Clinicians commonly work and make decisions under precise and stringent time constraints in demanding environments with incomplete information. Excessive choices create uncertainty and distraction leading to errors. Existing HIRS systems are not currently designed to identify what clinician process is underway or parse what data/information is needed at any particular point in a workflow or separate important ‘signals’ from not-so-important noise. As a result, HIRS designers tend to display too many choices, interface links, and other elements to ensure all possible use cases are covered. This creates a system in which “users” become distracted when interrupted and HIRS use becomes disorganized and confusing [106]. Better mechanisms are needed to retrieve and display information in a context- and/or clinician and patient-determined manner, which often means there has to be a clinician and patient-centric version of care.

Two recent studies show U.S. physicians spend nearly 2-hours on documentation for every hour of ‘in-person’ time with patients [42], [43]. Comprehensive regulatory reform is indispensable to reducing the impact of reimbursement regulations and policies on physician workflows. Healthcare systems in other industrialized countries are often cited for the ability to provide higher quality, more cost-effective care with better health outcomes compared to those in the United States [113]. Interestingly, clinical documentation in those countries largely omits the reimbursement and regulatory information that bloats American clinical notes, resulting in documentation which is, on average, four times shorter than in the US [5].

Patients are living longer and often present themselves with multiple complex interactive symptoms and preexisting problems. Working through a complete differential diagnosis can easily require scores, sometimes a hundred or more, diagnoses be considered and prioritized. Sixty percent of primary care physicians (PCPs) have contemplated the need for a complete HIRS overhaul. Only 8% of PCPs note the primary value of HIRS is clinically related [67]. At present, HIRS have proprietary source codes designed with “one size fits all” workflows and consisting of generic tasks and steps which do not accurately reflect clinicians’ mental models or the methodology in which clinicians actually provide care at the bedside and clinic [29]. Including a wide spectrum of clinician specialties, environments, and contexts in a few common pathways produce HIRS which force physicians and other clinicians to alter preferred workflows and cognitive styles developed based on years of training and practice to align with administrative, regulatory, or organizational HIRS workflows and requirements. The mismatch causes clinicians and physicians to perceive HIRS as disruptive and inefficient [29].

On the other hand, if the ground is constantly changing, unpredictable, and challenging, then care and workflow models may be rapidly evolving. How should HIRS/DHS systems and clinicians and patients and other health team members adapt to the future? In the TR, clinician burden use cases and challenges outline trends and changes to consider.

Many clinicians use multiple HIRS having differing interface designs, icon sets, and workflow steps conceivably creating additional patient safety and usability challenges [114]. An effective approach to mitigating the multiple interfaces would be the development of consensus interface-level design specifications supported by evidence-based principles of human-computer interface (HCI) design [114], [115]. Using standard HCI platform conventions to enable a familiar HIRS “look and feel” in different contexts has been very successful for improving safety in both the automotive and aviation industries. Yet, HIRS developers consistently argue such a HCI standard would stifle innovation, though examples from other industries do not support the claim. There is a shared responsibility of developers, clinicians, and user experience (UX) experts, researchers, and regulators to collaborate in developing HCI standards to improve usability and safety [115].

7. Summary

Healthcare HIRS products vary widely in incorporating and/or implementing HCI principles and user-centered design [116], [117]. At present, there is no international standard with which to

accurately measure HIRS HCI usability. Throughout the healthcare field, usability is typically addressed by self-attestation by HIRS product developers, and lack of standards and reporting creates a significant barrier for HIRS purchasers trying to directly compare the usability of HIRS products [115].

The inevitable variability involved in clinician practice requires HIRS to assist clinicians in aggregating, organizing, presenting, and using relevant context-specific patient information. This assistive role for HIRS should relieve clinicians from the burden of fetching each piece of context-specific information from different ‘drawers’ of the electronic health record ‘filing cabinet.’ Current HIRS adopt visually complex representations derived from prior paper-based records. The current WIMP (Windows, Icons, Menus, Pointers) form-based data entry paradigm, “requires clinicians to navigate deeply nested menus and browse through long pull-down lists that are neither filtered nor contextualized.” [55] Data is entered one bit at a time requiring multiple keystrokes, points, clicks, and scrolls. Data is sorted by the method used to generate the data rather than by the clinical problem the data relates to.

An important lesson of the last 15 years is clinician-patient interactions and physical and cognitive workflow processes are not orderly or linear enough to be well accommodated by current algorithmic methods and client server architectures, and the mismatch causes adverse burden consequences [29]. Clinician goals are to simplify, harmonize, and automate all non-clinical documentation and administrative responsibilities supporting clinician care delivery. Healthcare organizations have taken two approaches to the problems of clinician burden, distress, and burnout. The first approach has been to implement intensive team based approaches aimed at training physicians to use existing HIRS functionalities efficiently, building specialty-specific HIRS configuration adjustments and tools, and redesigning clinician workflows [118]. The second approach has been to create clinician wellness and resiliency programs focusing on mindfulness, meditation, exercise, sleep hygiene, and other well established stress management techniques from the psychology literature [108], [119]. Although each approach has value and can provide short term relief, neither is a long-term solution because they do not address the underlying root causes of burden: cognitive mismatch, HIRS’s poor HCI functionality and the use of HIRSs to add required activities of low clinical value to the clinician’s workload. The very term “burden” suggests the problem originates in the clinician, who somehow lacks the personal resources or resiliency to bear up against the pressures of the HIRS work environment. Most healthcare organizations are misaligned, at least to some degree, with the clinicians’ commitment of patient first [108], [119]. Burden and burnout originate more from dysfunction in the healthcare system than from clinicians. There is a need to start with helping clinicians to do what is now humanly impossible – i.e. process all data that must be processed to do the job of being a clinician well. This problem predates the advent of HIRS and should be a high priority of HIRS HCI design.

A promising long-term approach to improving clinical workflow is the application of HCI design [120], [121]. Entering data with mouse and keyboard remains inherently slow, frustrating and “clunky.” [122], [123] A comprehensive and standardized HCI initiative could engage clinician capabilities and restore the clinicians’ sense of empathy and connection with patients [122].

Monitoring and improving care quality, assuring clinicians meet appropriate standards of care, confirming care documented as provided is commensurate with healthcare reimbursement schemes and collecting structured, computable clinical data as the basis of a learning healthcare system are achievable goals. For clinicians to achieve improvements in the healthcare delivery system, clinicians must be allowed to focus on the patient and patient care, not data entry, administrative, regulatory, and financial processes much less relevant to patient care. Clinicians must also be provided with improved decision support tools that help to reduce cognitive load by improving the quality and usability of patient data. This includes organizing patient data by problem, coupling the problem-oriented patient data with peer reviewed, scientific knowledge, and more effectively providing patient and problem specific, evidence-based guidance options that are precise, timely, and focused on the problem the patient is facing.

Evolving evidence-based, AI-guided, health assistant chaperoned systems can also transfer much of the data collection, vetting, refinement, and analysis to patients and health assistants, present guidance options, and prepare documentation. Using patients, health assistants, and digital tools as force multipliers in the care process can free overworked clinicians to focus on the most human and rewarding aspects of clinical care: interacting with patients, reasoning more accurately, making better decisions, and improving healthcare outcomes. Accomplishing these systems over the next several years may require sustained HCI-based investment in HIRS to unlock the potential of information technologies leading to exponential improvements once investments are firmly established [124]. Serious clinician burdens are amplified by the current limitations of the HIRS. A comprehensive and standardized HCI initiative is required to reduce clinician burden arising from the various factors discussed in the TR including enormous volumes of RPM data, mismatch between limited human cognition and data to be considered, diversity of clinician practice models, layers of regulatory documentation requirements, poorly coordinated administrative reporting, decreasing staff to patient ratios, longer physical work hours, and the burden to assure coordination and communication of care plans accurately while still effectively supporting the patient [106].

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