

***Interoperability, Governance, and Quality of Care: A Comparative
Evaluation of Electronic Health Record Adoption in Estonia, Canada,
and the United States***

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Abstract:

This study examines how Electronic Health Records (EHRs) affect the quality of healthcare across Estonia, Canada, and the United States. Using a qualitative comparative approach, it analyzes how differences in legislation, governance, and digital infrastructure shape interoperability and user experience in each system.

The results show that Estonia's unified digital ecosystem enables seamless data exchange, while Canada's decentralized model leads to uneven progress between provinces. In the United States, mandated standards accelerated adoption but introduced challenges related to workflow and data security. Overall, meaningful improvements in care quality depend on strong interoperability, clear governance, and user-centered system design.

Keywords :

Canada; digital health; Electronic health records; Estonia; Healthcare Quality; Interoperability; United States.

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I. INTRODUCTION

Health systems worldwide are undergoing substantial structural and technological shifts driven by rapid digitalization and the increasing reliance on data-intensive tools to support clinical and managerial decision-making. Within this broader transformation, the Electronic Health Record (EHR) has emerged as a central digital infrastructure, reshaping how patient information is documented, accessed, exchanged, and utilized across different levels of care. By enabling timely and secure access to clinical data, EHRs hold the potential to enhance diagnostic accuracy, reduce preventable errors, and improve the overall efficiency of healthcare institutions. The World Health Organization (WHO) defines the EHR as “a comprehensive digital system for recording, exchanging, and retrieving individual health information efficiently,” underscoring its role as a foundation for intelligent, patient-centered, and sustainable health systems.

Despite these promises, the extent to which EHRs improve healthcare quality varies considerably across national contexts. Successful implementation depends not only on technology itself but also on governance structures, interoperability frameworks, institutional readiness, and user acceptance. While some countries have leveraged EHRs to achieve measurable improvements in safety, continuity of care, and system performance, others continue to struggle with fragmented infrastructures, inconsistent standards, and persistent concerns regarding privacy, security, and workload implications for clinicians.

The experiences of Estonia, Canada, and the United States illustrate three distinct models of national EHR adoption. Estonia represents an interoperability-by-design approach rooted in a unified digital identity ecosystem. Canada demonstrates the opportunities and limitations of a decentralized federal system, where progress varies significantly among provinces. The United States follows a market-driven model reinforced by legislative mandates and financial incentives, leading to rapid diffusion alongside notable variability in integration and usability.

Against this background, the present study seeks to conduct a critical comparative analysis of EHR implementation in these three countries, examining how digital infrastructures, governance arrangements, and interoperability strategies have shaped healthcare quality outcomes. The study aims to extract key lessons that may inform ongoing digital health reforms—particularly in countries seeking to build resilient, equitable, and patient-centered EHR ecosystems.

Accordingly, the study is guided by the following **main research question**:

To what extent has the implementation of Electronic Health Records (EHRs) contributed to improving healthcare quality in Estonia, Canada, and the United States?

From this central question, three sub-questions emerge:

1. What technical and organizational characteristics distinguish EHR implementation in each country, and how have these features influenced system performance?
2. How has EHR adoption affected key healthcare quality indicators such as safety, efficiency, continuity of care, and patient satisfaction?
3. What challenges have accompanied implementation efforts in each national context, and what strategies have been employed to overcome them?

1. Conceptual and Theoretical Framework of Electronic Health Records (EHRs) and Their Relationship to Healthcare Quality

Electronic Health Records (EHRs) constitute a foundational element in the ongoing digital transformation of health systems. By enabling secure, accurate, and readily accessible patient information, EHRs support a wide range of quality-related outcomes, including improved clinical decision-making, reduced medical errors, enhanced coordination of care, and more efficient use of resources. This section presents the conceptual bases of the EHR and examines its theoretical relationship to healthcare quality.

1.1. Theoretical Framework of the Electronic Health Record (EHR)

The emergence and evolution of the EHR reflect a gradual shift from fragmented, paper-based documentation toward integrated digital systems capable of supporting real-time clinical workflows. Early digitization efforts in the 1980s laid the groundwork for the development of structured electronic platforms, driven by the need to overcome inefficiencies in paper records and supported by growing attention to interoperability, governance, and data security. These developments were reinforced by professional organizations that promoted standardized documentation practices and frameworks for information exchange. However, the transition was not without challenges: healthcare institutions had to invest in staff training, system integration, and robust approaches to privacy and security management, all of which remain central to contemporary EHR implementation.

1.1.1. Historical Development

a. First Stage: Initial Emergence (Late 1960s–Early 1970s)

EHR foundations emerged with Lawrence L. Weed's Problem-Oriented Medical Record (POMR), which introduced a structured method for documenting clinical reasoning. Weed's subsequent PROMIS system represented one of the earliest digital attempts to apply this model in practice (Wright, Sittig, , Ash, & Sharma, 2014)

b. Second Stage: Early Systems and Functional Adoption (1980s–Early 1990s)

In the 1980s and 1990s, early institutional systems such as the Regenstrief Medical Record System (RMRS) demonstrated the feasibility of using a shared, computerized clinical database to support routine documentation and clinical decision-making across multiple care settings (McDonald, Overhage, & Dexter, The Regenstrief Medical Record System: A quarter-century experience, 1999)

c. Third Stage: The Internet Era and Interoperability Standards (1990s)

During the 1990s, the advent of the internet and the increasing need for data exchange between healthcare institutions drove the development and adoption of interoperability standards such as HL7 and DICOM. These standards enabled more effective electronic communication and data sharing, laying the foundation for broader, more integrated EHR systems in the following decades (Benson & Grieve, 2021)

d. Fourth Stage (2000–2010): Legislative Expansion and System-Level Integration

Beginning in the early 2000s, national EHR programs emerged worldwide to integrate health information systems and improve care quality. Successful implementation depended on robust governance, clear regulatory frameworks, and investment in interoperability infrastructure and workforce readiness (Organisation for Economic Co-operation and Development (OECD), 2023)

e. Fifth Stage (2010–Present): Interoperability and Digital Integration:

Since 2010, EHR development has focused on achieving advanced interoperability, driven largely by the emergence of the FHIR standard, which enabled flexible, API-based data exchange across health systems (Mandel, Kreda, Mandl, Kohane, & Ramoni, 2016). This shift strengthened cross-platform compatibility and supported new clinical and analytical applications. At the policy level, the European Health Data Space (EHDS) initiative aims to harmonize interoperability and data-governance frameworks across EU member states (European Commission, 2022). Together, these developments positioned EHRs as integrated, standards-driven systems central to coordinated care and data-enabled health innovation.

1.1.2. The Nature of the Electronic Health Record (EHR):

The Electronic Health Record (EHR) constitutes a secure, structured, and longitudinal digital repository of patient information. Its conceptual evolution and functional design underpin its role as a central mechanism for enhancing quality, coordination, and efficiency within modern healthcare systems.

a. Definition of the Electronic Health Record (EHR):

The Electronic Health Record (EHR) represents a structured, secure, and longitudinal digital repository that supports the delivery of modern healthcare. Unlike the Electronic Medical Record (EMR), which remains limited to a single organization (Carter, 2001), the EHR facilitates cross-institutional data exchange and incorporates advanced functionalities such as interoperability and clinical decision support (Amatayakul, 2006). International frameworks reinforce this definition: the World Health Organization describes the EHR as “**An electronic health record (EHR) is a longitudinal electronic record of patient health information generated by one or more encounters in any care delivery setting.**” (World Health Organization, 2016, p. 19), while ISO/TR 20514 defines it as “**The primary purpose of ISO’s family of EHR standards is to maximize interoperability between electronic records and systems that are specifically intended to be shareable, irrespective of the technologies they use and the platforms on which they reside.**” (ISO/TR 20514:2005, p. 3)

The conceptual roots of the EHR can be traced to Weed’s introduction of the Problem-Oriented Medical Record (Weed, 1968), which structured clinical documentation around patient problems. This foundation later evolved into more advanced digital architectures, most notably the Regenstrief Medical Record System, which McDonald explicitly defined as a shareable, computable clinical database able to support automated decision-making (McDonald C. , et al., 1999). Expanding this perspective, Payne conceptualized the modern EHR as an integrated knowledge platform

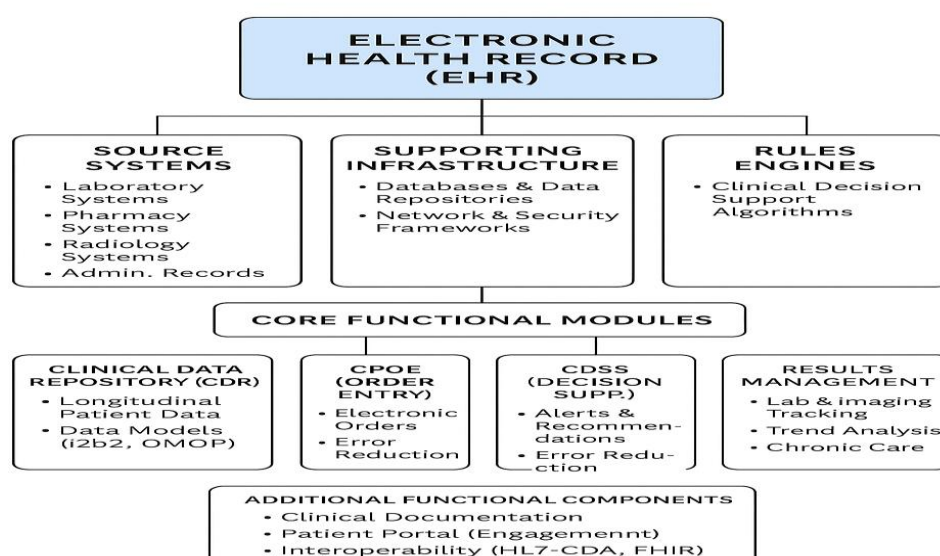
that facilitates collaboration, supports longitudinal analysis, and enhances clinical decision processes (Payne, et al., 2014)

In summary, the EHR is not merely a digital transcription of paper charts but a transformative data-driven infrastructure that strengthens clinical consistency, improves monitoring, and supports sustainable quality enhancement.

b. Core Components of the Electronic Health Record (EHR):

Functional modules within Electronic Health Record (EHR) systems constitute essential components that directly enhance patient safety and clinical quality. Computerized Physician Order Entry (CPOE) systems, for example, have demonstrated substantial reductions in medication errors—reported in some studies to reach up to 55%—highlighting their critical role in minimizing prescribing risks (Ammenwerth, 2008). In parallel, Clinical Decision Support Systems (CDSS) further strengthen the clinical workflow by improving clinician performance and supporting consistent, evidence-based decision-making (Jaspers, Smeulers, & Vermeulen, H , 2011) Complementary tools such as results management, clinical documentation modules, and patient portals also contribute to improved communication, continuity of care, and patient engagement (Irizarry, DeVito A, & Curran , 2015). At the technical foundation, interoperability standards—most notably HL7-CDA and the more recent HL7-FHIR—provide the structured, secure, and semantically consistent framework that enables cross-institutional data exchange and underpins the broader interoperability ecosystem (HL7 International, 2023).

Figure 1. Architecture and Core Components of the Electronic Health Record (EHR)



Source: Adapted by the researchers from the cited literature.

1.2. The Electronic Health Record (EHR) as a Tool for Improving the Quality of

Healthcare Services:

According to the WHO, healthcare quality includes six dimensions—safety, effectiveness, efficiency, patient-centeredness, timeliness, and equity—each of which can be strengthened through well-designed Electronic Health Records (EHRs) (World Health Organization, 2018, World Health Organization, 2020). When integrated effectively into clinical workflows, EHRs support coordinated, data-driven care across these domains.

- a. **Safety:** Core EHR functionalities such as CPOE and CDSS help reduce medication errors and improve safety, with systematic reviews confirming notable gains in safety indicators (Campanella, Lovato, Marone, & Fallacara, 2016, Mancuso, A., Ricciardi, W., & Specchia, M. L.)
- b. **Effectiveness and Efficiency:** EHRs promote adherence to guidelines, prevent duplicate testing, and improve operational performance, contributing to shorter procedures and reduced hospital stays (Campanella, Lovato, Marone, & Fallacara, 2016, Mancuso, A., Ricciardi, W., & Specchia, M. L.).
- c. **Patient-Centeredness:** Patient portals enhance access to personal health information, communication with providers, and engagement in shared decision-making (Neves, 2020)
- d. **Timeliness:** Real-time data, alerts, and reminders accelerate clinical workflows and reduce delays in care delivery (Campanella, Lovato, Marone, & Fallacara, 2016, Mancuso, A., Ricciardi, W., & Specchia, M. L.)
- e. **Equity:** Despite their benefits, disparities in digital literacy and access limit equitable use of EHR features, particularly patient portals (Neves & Freise, 2020) Overall, EHRs have the potential to enhance all six WHO-defined quality dimensions, provided that implementation is supported by strong governance and capacity-building efforts.

2. A Critical Analysis of International Experiences in Implementing Electronic Health Records (EHRs):

This section explores how different countries around the world have approached the implementation of Electronic Health Records (EHRs), not just from a technical angle, but as real national journeys shaped by the people, institutions, and decisions behind them. By focusing on three well-known examples—Estonia, Canada, and the United States—the section highlights how each country followed its own path in digital health transformation, influenced by its unique governance structures, technological capabilities, and policy environments. Through comparing these experiences, the analysis sheds light on how choices related to interoperability, leadership, and stakeholder collaboration can determine whether national EHR initiatives become effective, scalable, and sustainable. Ultimately, these cases offer practical lessons that can guide other health systems as they work toward their own digital health goals.

2.1. The Estonian Experience with the Electronic Health Record (EHR)

2.1.1. Overview of the National EHR System:

Estonia is widely recognized as one of the most advanced examples of “interoperability by design,” having launched a nationwide Electronic Health Record (EHR) in 2008, tightly integrated with the national digital identity infrastructure (e-ID). This integration made secure authentication and traceable access inherent components of the national digital architecture. Central to this system is **X-Road**, the government-wide

data exchange backbone that links clinical and administrative databases under unified security and access policies, ensuring encrypted, timestamped, and auditable data flows (Metsallik, 2018).

Data integrity is further reinforced through the **Keyless Signature Infrastructure (KSI)**, a blockchain-based mechanism that provides tamper-evident, time-stamped verification independent of long-term secret keys (Semenzin, Rozas, & Hassan, 2022). Collectively, e-ID, X-Road, and KSI form a coherent trust framework that supports secure authentication, transparent data tracking, and proven long-term integrity.

2.1.2. Evolution and Development

Estonia's digital health development has progressed through a structured and cumulative trajectory. Following the nationwide launch of the Electronic Health Record in 2008, national efforts increasingly emphasized standardized data exchange, drawing on internationally recognized formats to support consistent document interoperability across providers (Metsallik, Ross, Draheim, & Piho, 2018). By the mid-2010s, attention shifted toward strengthening auditability and long-term reliability through the operational deployment of the Keyless Signature Infrastructure (KSI), enabling independent, tamper-evident, time-stamped validation of health data.

Operational indicators point to considerable growth in system utilization. The volume of documents transmitted through the Estonian Health Information System increased substantially after 2016, and both patient and professional queries rose significantly—reflecting a broader transition from early technological readiness to routine, everyday clinical use (Metsallik, Ross, Draheim, & Piho, 2018). On the patient side, the national health portal has matured into a widely used interface for reviewing prescriptions, laboratory results, imaging reports, and visit summaries. A large Nordic comparative study (n = 29,334) found that usability—particularly ease of use and perceived task control—was a major predictor of sustained patient engagement. Differences between countries were attributed primarily to interface and workflow design rather than to underlying technological infrastructure (Kujala, et al., 2024)

2.1.3. Infrastructure and Societal Engagement

Estonia's digital health infrastructure is underpinned by a governance model that prioritizes interoperability and security. Through X-Road, the national data exchange layer, public and private entities are able to share information securely and in near real time, supported by mandatory encryption, logging, and time-stamping mechanisms (Metsallik, Ross, Draheim, & Piho, 2018)

At the societal level, the national patient portal has strengthened transparency and encouraged active participation in care. Evidence from large Nordic studies shows that usability—particularly ease of use and perceived task control—is closely linked to sustained patient engagement and satisfaction, highlighting the importance of task-oriented, user-centred design (Kujala, et al., 2024). Operationally, Estonia has progressed from early adoption to full, system-wide integration of its digital health services. Evaluations indicate continuous increases in documentation volume and user activity, reflecting improvements in data completeness and the practical value of the system for clinical decision-making. Additionally, aligning digital architecture with national financing and regulatory frameworks has helped reduce duplication, streamline workflows, and support consistent provider compliance (Metsallik, Ross, Draheim, & Piho, 2018)

Table (1) Key Performance Indicators of Estonia's EHR (2020–2023)

Indicator	Value (Approx.)	Source
National coverage of digital health records	~100% nationwide EHR coverage since 2008	(e-Estonia, n.d)
Share of health data digitised	~99% of all health data digitised	(Numa, n.d)
Share of prescriptions issued electronically (e-Rx)	~100% e-Prescriptions nationwide	(e-Estonia, n.d)
EU composite eHealth maturity score	~98% (Top EU-27 performer)	(European Commission, 2024)
Citizen access – “Access opportunities”	100% maturity score	(European Commission, 2024)

Source: Indicators are approximate and based on verified national and EU-level reports (2023–2024). Sources include official e-Estonia documentation and European Commission Digital Decade eHealth Indicator Studies.

Estonia's national EHR ecosystem exhibits a remarkably high level of digital maturity. The country has achieved full population coverage, near-universal use of e-prescriptions, and consistently strong usability outcomes, as confirmed by large-scale Nordic benchmarking studies. Supported by X-Road—its robust national interoperability backbone—and advanced data-integrity mechanisms, Estonia's digital health infrastructure provides a secure, efficient, and patient-centered environment. Together, these elements enable high-quality, data-driven care and position Estonia as one of Europe's leading models in digital health implementation.

2.1.4. Structural and Regulatory Challenges:

Despite Estonia's advanced digital infrastructure, several structural and regulatory challenges continue to influence the long-term sustainability of its national EHR system. First, large-scale Nordic evidence shows that age and digital literacy remain significant predictors of patient-portal adoption, highlighting the need for inclusive design and targeted digital-skills programs aimed at reducing disparities in patient engagement (Kujala, et al., 2024). Second, although Estonia fully complies with GDPR, recent analyses emphasize that lawful data reuse requires additional governance layers—including granular authorization, least-privilege access, and systematic de-identification—to balance data-driven innovation with privacy protection (Vukovic & Chaudhary, 2022). Third, while X-Road substantially reduces technical fragmentation, smaller private clinics still face difficulties meeting interoperability and cybersecurity requirements, underscoring the necessity of standardized support mechanisms and capacity-building initiatives (Metsallik, Ross, Draheim, & Piho, 2018).

Finally, studies on Estonia's digital infrastructure underline that maintaining and upgrading national platforms such as the EHR and the Keyless Signature Infrastructure (KSI) depends on stable long-term financing models aligned with measurable value outcomes (Semenzin, Rozas, & Hassan, 2022).

2.1.5. Critical Reflection:

Estonia's digital health trajectory illustrates how a coherent national architecture—anchored in e-ID, X-Road, and KSI—can institutionalize trust, security, and interoperability at system scale. This layered infrastructure demonstrates that digital transformation succeeds when foundational design choices are aligned with long-term governance and societal needs. Yet, despite Estonia's status as a global benchmark,

several structural vulnerabilities persist, including demographic disparities in digital engagement, heightened regulatory scrutiny over secondary data use, uneven digital skills across user groups, and the growing financial and operational burden of maintaining national platforms. Collectively, these challenges suggest that the sustainability of Estonia's EHR ecosystem depends not only on advanced technology, but on adaptive governance, continuous capacity-building, and inclusive, citizen-centered implementation strategies.

2.2. The Canadian Experience with Electronic Health Records:

2.2.1. Overview of the Digital Health System in Canada:

Canada's digital health system operates within a highly decentralized governance structure, where each province and territory independently designs, funds, and manages its own digital health architecture. This federal model has enabled locally tailored innovation but has also resulted in fragmentation, uneven interoperability, and variation in the maturity of electronic health systems across the country. To strengthen national coordination, the federal government introduced Bill C-72—the *Connected Care for Canadians Act*—in June 2024, aiming to prohibit data blocking by health-IT vendors and to mandate common interoperability standards that support seamless, cross-jurisdictional data exchange (Canada Health, 2024; Legislative Summary of Bill C-72, 2024).

From a patient perspective, empirical studies show that digital tools such as patient portals have improved access to information, transparency, and communication with clinicians; however, digital divides persist, particularly among older adults and individuals with limited eHealth literacy (Deshpande, Arora, Vollbrecht, Meltzer, & Press, 2023). Additionally, evidence from Alberta highlights that even well-designed portals face usability barriers and trust concerns among early adopters and non-users alike, pointing to the importance of inclusive, user-centred digital service design (Santos, et al., 2021). Taken together, Canada's experience illustrates how decentralized governance can foster innovation while simultaneously creating coordination challenges that require strong federal policy, harmonized standards, and sustained investment in both technology and digital literacy.

2.2.2. Infrastructure, Operational Dynamics, and Community Engagement

Canada's digital health infrastructure operates within a decentralized, province-led model that fosters local innovation but also produces fragmentation and interoperability gaps. In response, the federal government introduced the *Connected Care for Canadians Act* (Bill C-72) in 2024 to prohibit data blocking and mandate unified national interoperability standards (Canada. Department of Health, 2024, Parliament, 2024). From a citizen standpoint, patient portals have improved transparency and access to personal health information, yet digital divides linked to age and limited eHealth literacy continue to restrict equitable usage (Deshpande, Arora, Vollbrecht, Meltzer, & Press, 2023). At the professional level, persistent gaps in digital competencies—especially among newly graduated nurses due to limited hands-on exposure to EHR systems—underscore the need to strengthen digital health training within nursing education and clinical practice (Kleib, Simpson, Rhodes, & Bowen, 2019). Overall, sustainable digital transformation in Canada requires not only technological infrastructure but also coordinated governance, equitable participation, and continuous workforce development.

Table 2: Performance Indicators of the Canadian Electronic Health Record (EHR) System, 2023–2024**Source: Compiled by the researchers based on CIHI, Statistics Canada, Prescribe IT, and**

Indicator	Value (2023/2024)	Source
Use of EMR among family physicians	93% (2022; published 2023)	(Canadian Institute for Health Information, International survey results reveal challenges experienced by family doctors in Canada)
Canadians (≥15 years) who accessed their electronic health information (past 12 months)	51% (2023)	(Statistics Canada, 2023)
Pharmacies enrolled in PrescribeIT	8,540 pharmacies (≈70% of all licensed pharmacies)	(Canada Health Infoway / PrescribeIT, 2025)
Prescribers enrolled in PrescribeIT	20,784 prescribers (2024)	Canada Health Infoway /) (2025 •PrescribeIT
Hospitals implementing PrescribeIT	11 hospital sites (2024)	Canada Health Infoway /) (2025 •PrescribeIT
Canadians who received at least one virtual primary-care visit	1 in 3 Canadians (published 2024)	CIHI Virtual Primary Care: Impacts and Opportunities (2024)
Interoperable access to laboratory results among family physicians	55% (2022; published 2023)	Canadian Institute for) (2023 •Health Information

NAPRA data.

The performance indicators presented in Table 2 reveal a mature yet unevenly integrated digital health ecosystem in Canada. High EMR adoption among family physicians (93%) and near-universal digital pharmacy participation through PrescribeIT demonstrate strong clinical digitization. However, only 51% of Canadians aged 15 and older accessed their electronic health information in the previous year, reflecting persistent digital divides that limit citizen-centered engagement. Additionally, while one in three Canadians received virtual primary care, interoperability gaps remain evident, with only 55% of family physicians having electronic access to laboratory results. These findings suggest that Canada's digital health landscape combines strong technological infrastructure with ongoing barriers to system-wide integration, equity, and consistent user engagement. Sustained progress will require nationally coordinated standards, improved cross-jurisdictional interoperability, and targeted digital-literacy efforts.

2.2.3. Evolution of EHR Adoption in Canada

Canada's journey in adopting electronic health records has unfolded in three broad phases. The first phase (2001–2010) was a foundational period led by Canada Health Infoway, during which federal investments supported early digitization and the rollout of electronic systems in several large provinces. The second phase (2010–2019) saw the widespread diffusion of EMR systems in primary care and their growing use to monitor performance and support quality-improvement initiatives, particularly in chronic disease

management and preventive care (Barbazza , et al., 2021). Since 2020, a third acceleration phase has been driven by the COVID-19 pandemic and renewed federal efforts—such as the proposed C-72 “Connected Care for Canadians Act”—to reduce data silos and strengthen interoperability across jurisdictions. Contemporary analyses suggest that provinces like Ontario and Alberta have reached high levels of EMR/EHR adoption, while northern and rural regions continue to lag due to persistent infrastructural and technical constraints ((Barbazza , et al., 2021, Jarvis , et al., 2023).

2.2.4. Structural and Regulatory Challenges:

Despite clear progress, Canada’s EHR landscape remains shaped by structural and regulatory fragmentation, as inter-provincial differences in policy, infrastructure, and digital capacity continue to obstruct a fully interoperable pan-Canadian ecosystem (Jarvis , et al., 2023). Efforts to advance digital innovation must also be balanced against increasingly stringent privacy and data-protection requirements, which demand robust and transparent data-governance frameworks (Vucovic , Ivankovic , Habl , & Dimnjakovic , 2022). These system-level constraints are compounded by limited digital competencies among healthcare professionals and persistent socio-digital inequalities that restrict equitable patient use of portals and other online (Alpert , Paolucci , & Forchuk , 2023; Kleib, Simpson, Rhodes, & Bowen, 2019). Finally, concerns over the long-term financial sustainability of maintaining and upgrading digital infrastructures underscore the need to align ongoing investment in EHRs with demonstrable gains in quality, equity, and overall system performance (Jarvis , et al., 2023)

2.2.5. Critical Appraisal of the Canadian Experience: The Canadian experience demonstrates that effective EHR implementation is fundamentally a question of governance rather than technology alone. Within a model of cooperative federalism, federal–provincial arrangements stimulate local innovation but simultaneously hinder the emergence of a coherent, interoperable national ecosystem. Sustained digital-health progress therefore requires three interdependent conditions: strengthening digital competencies across the healthcare workforce, rebuilding public trust through transparent and accountable data-governance practices, and introducing clear national interoperability requirements that can gradually reduce provincial disparities. In this context, the proposed Bill C-72 can be seen as a potential inflection point, with the capacity—if effectively implemented—to narrow existing digital gaps and support a more cohesive and equitable digital health landscape in Canada.

3.2 The United States Experience: Legislative Acceleration and Market-Driven Digitalization (Condensed Version)

3.2.1. Legislative Acceleration and the Rise of Meaningful Use

Over the past twenty years, the U.S. healthcare system has undergone a fast-moving digital transformation, driven by rising costs and the imperative to improve quality and patient safety. A pivotal moment in this evolution was the 2009 Health Information Technology for Economic and Clinical Health (HITECH) Act, enacted under the American Recovery and Reinvestment Act (ARRA), which established a national framework for broad-scale adoption of electronic health records (EHRs) (Adler-Milstein & Jha, 2017). The law introduced the *Meaningful Use* program, emphasizing that technology adoption must translate into improved clinical performance and health outcomes (Wager , Lee , & Glaser , 2022). Although the U.S. healthcare system is highly decentralized, the HITECH Act served as a strong integration point between federal policy and market forces, with the private sector playing a key role in designing and implementing certified EHR systems (Adler-Milstein & Jha, 2017; Wager et al., 2022). Incentive payments exceeding USD 30 billion (and subsequent phased penalties for non-

compliance) created a powerful economic driver for hospitals and providers to adopt and meaningfully use certified EHR technologies (Adler-Milstein & Jha, 2017). As documented, hospital adoption of EHR systems rose dramatically: from less than 10 % in 2008 to over 85 % by 2015, marking one of the fastest digital transitions in healthcare globally (Adler-Milstein & Jha, 2017).

3.2.2. Technological Infrastructure and the Role of the Private Sector

such as Epic, Cerner, and Meditech shaping how clinical data are captured and exchanged across hospitals and ambulatory settings (Wager , Lee , & Glaser , 2022). Supported by federal incentives and strong market competition, investment in digital health technologies expanded significantly, accelerating nationwide EHR adoption. Interoperability standards—particularly HL7 and FHIR—became essential for enabling structured and secure data exchange.

According to ONC reports, the national transition unfolded in three main phases. The first phase (2009–2014) was marked by rapid EHR uptake driven by HITECH Act incentives. The second phase (2017–2019) saw broader use of advanced functionalities such as patient portals, information-exchange networks, and API-enabled services (Office of the National Coordinator for Health Information Technology, 2019). The third phase (2020–2024) has focused on nationwide interoperability and analytics under the 21st Century Cures Act, supported by USCDI standards, FHIR-based APIs, and emerging national exchange networks (Office of the National Coordinator for Health Information Technology, 2024)

Table 04. Key Performance Indicators of the U.S. Electronic Health Record (EHR) System – Latest Available Data

Indicator	Value (latest available)	Source
Percentage of non-federal acute care hospitals with a certified EHR system	96% (2021)	(Office of the National Coordinator for Health Information Technology, 2021)
Percentage of office-based physicians using EHR systems	88.2% using any EHR; 77.8% using certified EHR (2021)	(Centers for Disease Control and Prevention, 2021)
Hospitals engaging in all four interoperability domains (send, receive, find, integrate)	70% (2023)	(Office of the National Coordinator for Health Information Technology, 2023)
Individuals offered and accessing their online medical record or patient portal	≈60% (2022)	(Office of the National Coordinator for Health Information Technology, 2022)
Scale of e-prescribing adoption	2.54 billion e-prescriptions filled (2022); virtually all pharmacies enabled (2024)	(Surescripts, 2023)
Cumulative federal funding authorized for HITECH EHR incentive programs	≈36 billion USD (since 2009)	(U.S. Department of Health and Human Services, 2023)
Percentage of non-federal acute care hospitals with a certified EHR system	96% (2021)	(Office of the National Coordinator for Health Information Technology, 2021)/
Percentage of office-based physicians using EHR systems	88.2% using any EHR; 77.8% using certified EHR (2021)	(Centers for Disease Control and Prevention, 2021)

The Source: Table prepared by the authors based on the cited sources listed in the right-hand column.

The performance indicators presented in this table illustrate the maturity and scale of digital transformation within the United States health system. Nearly universal adoption

of certified EHR systems among non-federal acute care hospitals and high uptake among office-based physicians demonstrate strong foundational digital capacity. Interoperability continues to advance, with 70% of hospitals now engaged in all four core exchange domains, reflecting steady alignment with federal policy efforts to promote information sharing. Despite broad availability of patient portals, actual patient engagement remains moderate, underscoring persistent gaps in digital literacy and equitable access. Meanwhile, the widespread expansion of electronic prescribing and sustained federal investment through programs such as HITECH highlight the long-term policy commitment driving digital infrastructure. Overall, these indicators reveal a highly digitized yet still evolving ecosystem, where progress in interoperability, patient engagement, and data-driven care continues to be shaped by regulatory action, vendor innovation, and ongoing efforts to ensure equitable digital participation.

3.2.3. Structural and Organizational Challenges

Despite very high adoption levels of EHRs in U.S. hospitals, several structural and organizational challenges continue to constrain the system's overall performance. First, economic evaluations indicate that EHR implementation and maintenance remain capital-intensive undertakings, with substantial costs related to infrastructure, workflow redesign, and ongoing optimization—while evidence on financial returns remains mixed and highly context-specific (Nguyen, Wright, Woods, & Simpsonn, 2022; Modi & Feldman, 2022))

Second, a growing body of research links EHR usability issues, documentation burden, and inbox management with clinician stress and burnout. Systematic reviews demonstrate that EHR-related workload is a significant contributor to burnout across multiple clinical settings (Yan, Jiang, Harbin, & Tolbert, 2021). Recent U.S. survey data also show that perceived EHR usability and after-hours EHR work are strongly associated with burnout among more than 10,000 family physicians (Rotenstein, Hendrix, Phillips, & Adler-Milstein, 2024) Third, as healthcare has become increasingly digitized, cybersecurity risks have intensified. National analyses of reported breaches demonstrate hundreds of large-scale incidents affecting tens of millions of patient records, with hacking and IT intrusions emerging as dominant causes (Ronquillo, Winterholler, Cwikla , Szymanski, & Levy, 2018). Taken together, these challenges underscore the need for EHR strategies that balance regulatory requirements with usability, workforce well-being, and robust information-security governance.

3.2.4. Critical Analysis of the U.S. Experience

The U.S. experience with EHR implementation reveals a model driven by strong federal incentives and competitive market dynamics, which succeeded in accelerating adoption but also introduced lasting structural tensions. Rapid digital expansion often outpaced the ability of health organizations to absorb new systems effectively, resulting in uneven benefits and persistent fragmentation across institutions. Despite technological sophistication, many providers continue to struggle with usability issues, documentation burden, and workflow disruption, raising questions about the balance between regulatory compliance and real clinical value. At the same time, the increasing digitization of health information has heightened security risks, underscoring the need for more resilient infrastructures. Overall, the U.S. case suggests that future progress depends less on expanding functionality and more on developing human-centered, secure, and effectively integrated digital environments that genuinely support clinical practice.

I. Methods and Materials

This study adopts a qualitative, analytical, and comparative design to examine how Estonia, Canada, and the United States have implemented Electronic Health Records (EHRs), and how these strategies have shaped healthcare quality. A descriptive–comparative logic inspired by Qualitative Comparative Analysis (QCA) was used to interpret structural, technical, and governance differences across the three systems.

Three complementary approaches guided the research. The *comparative approach* ensured consistent evaluation across unified analytical dimensions, while the *critical–analytical approach* enabled interpretation of systemic variations, their operational implications, and their links to governance and interoperability. Data were sourced from peer-reviewed journals (e.g., JAMIA, IJMI, BMJ Open), international organizations (WHO, OECD, World Bank), and official national reports (e.g., ONC, Canada Health Infoway, Estonian e-Governance sources), in addition to regulatory frameworks such as GDPR and HITECH.

The comparative framework assessed five dimensions: (1) legislative and regulatory foundations; (2) digital infrastructure and interoperability readiness; (3) adoption and usage among clinicians, patients, and institutions; (4) effects on healthcare quality (based on WHO’s six dimensions); and (5) structural and institutional challenges across the three national contexts.

II. Results and Discussion

1. Legislative and Regulatory Foundations

Estonia’s strategy reflects interoperability-by-design: national e-ID, X-Road, and KSI create alignment between law, architecture, and implementation. The U.S. relies on regulatory levers—HITECH, USCDI, TEFCA—to drive adoption and enforce standards, resulting in high uptake but greater administrative and vendor complexity. Canada operates between the two models: cooperative federalism supports provincial innovation, yet the absence of enforceable national standards perpetuates uneven digital maturity across jurisdictions.

2. Digital Infrastructure and Interoperability

Estonia’s unified infrastructure supports real-time, cross-sector data exchange at low integration cost. In the U.S., fragmentation persists despite advanced systems; widespread FHIR-based APIs have strengthened connectivity, yet full interoperability remains incomplete. Canada shows strong infrastructures in major provinces, but rural and northern regions still struggle with limited capacity, producing intra-national inconsistencies.

3. Adoption and Usage Patterns

EHR adoption is highest in the U.S. due to strong policy incentives, followed by Estonia where national identity-based workflows have supported near-universal adoption. Canada displays uneven uptake—primary-care adoption is high, yet citizens’ electronic access to their own information remains comparatively limited. Patient engagement mirrors these trends: Estonia shows strong portal engagement, while Canada continues to face socio-digital inequalities.

4. Effects on Healthcare Quality

Across all three systems, EHRs improve safety, effectiveness, and coordination when integrated into clinical workflows. Estonia demonstrates measurable gains in continuity of care and reductions in duplication. Evidence from the U.S. indicates improvements in guideline adherence and chronic-disease management, although usability and

documentation burden remain barriers. Canada shows positive—but heterogeneous—quality improvements, strongly dependent on provincial digital capacity and system integration.

5. Persistent Structural and Operational Challenges

Each system faces critical obstacles:

United States: high implementation costs, clinician burnout, and recurrent cybersecurity incidents.

Canada: persistent inter-provincial disparities, variable digital competencies, and uncertainty regarding long-term financial sustainability.

Estonia: digital divides, ongoing security upgrades, and integration challenges for smaller providers.

These challenges confirm that digital maturity requires continuous investment, adaptive governance, and sustained workforce development.

6. Cross-Country Lessons

The comparative analysis shows that successful EHR ecosystems combine: foundational interoperability embedded in system architecture (Estonia), enforceable national standards that align diverse markets (United States), and federal coordination that enables—but also balances—local innovation (Canada).

Across all contexts, usability and workflow alignment predict adoption more reliably than technical sophistication. Reducing documentation burden and strengthening digital literacy for both professionals and patients emerge as essential conditions for long-term sustainability.

III. Conclusion:

The comparative analysis of Estonia, Canada, and the United States shows that the adoption of Electronic Health Records (EHRs) is not a purely technical process, but the visible outcome of deeper interactions between legislative frameworks, digital infrastructures, and broader socio-institutional contexts. Each country's trajectory reflects a distinct combination of governance model, policy instruments, and capacity to translate digital strategies into routine clinical practice.

In Estonia, early political commitment and a coherent national digitalization agenda enabled the emergence of a highly integrated, secure, and interoperable EHR ecosystem. This configuration supports relatively uniform service delivery and robust use of data for care coordination and analytics, even as questions of sustainable financing, continuous upgrading, and evolving privacy requirements remain active policy challenges.

The Canadian case illustrates the double-edged nature of cooperative federalism in digital health. Decentralization has created space for local experimentation and provincial innovation, yet has also produced fragmentation and delayed the realization of nationwide interoperability. As a result, the potential value of health data at the national level—particularly for equity-oriented planning and quality monitoring—remains only partially realized.

In the United States, strong regulatory and financial levers—especially under the HITECH framework—were decisive in rapidly scaling EHR adoption and stimulating a highly competitive vendor market. This has driven substantial gains in technological sophistication, but has also generated persistent heterogeneity in system design, gaps in interoperability, and inequities in access and quality across regions and population groups.

Taken together, the findings indicate that the relationship between EHR adoption and healthcare quality is neither automatic nor linear. EHRs function as enabling infrastructures only when institutional readiness, governance arrangements, and change-management capacities are aligned. Meaningful improvements in quality depend on performance in interoperability, sustainable financing, robust data governance and privacy protection, and the active engagement of clinicians and patients in digital care pathways.

From a policy perspective, several cross-cutting lessons emerge. First, unified digital architectures and shared technical standards—as illustrated by Estonia—can substantially reduce fragmentation and integration costs. Second, balancing central coordination with local flexibility—as in Canada—is essential to ensure both responsiveness and system-wide coherence. Third, regulatory and financial incentives—as in the United States—can accelerate adoption, but must be designed to avoid reinforcing administrative burden or widening digital divides. Finally, across all contexts, public trust in EHR systems rests on credible privacy safeguards, transparent data practices, and visible accountability.

Looking ahead, the future of EHRs lies in embracing a socio-technical perspective that deliberately aligns digital design with public policy objectives. Building sustainable, equitable, and high-quality digital health ecosystems will require continued investment in shared infrastructure, convergence around common data standards, and adaptive regulatory frameworks capable of evolving with innovation. Under these conditions, EHRs can serve not only as repositories of information, but as strategic instruments for improving care quality, strengthening system performance, and advancing patient-centred health systems at both national and global levels.

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