Interoperability Challenges Between Micro-level EMR system and the Macro level EHR System (ABDM): A Systematic Review Approach

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Abstract: Interoperability challenges were different in context, depending upon the integration of the modules, levels (micro-meso-macro), types (foundational, technical, semantic, syntactic, etc..), HIS, EMR and EHR. It plays an important role in healthcare settings for seamless exchange of secured data, across different settings. Different countries solved the interoperability issues in different situations, whereas in India, it has been proposed to solve by using the Ayushman Bharat Digital Mission(ABDM) by the Government of India. Methods: The current study was conducted to review the published data on the interoperability challenges between the EMR System, at the micro level and the EHR systems at the macro level, similar to ABDM, across the world. Using keyword search techniques, AND, OR, NOT, +,|,-, * and different options provided by six different sources of databases were searched for related articles. The identified papers were screened and reviewed, based on title, and abstractat different stages which were relevant and valid. Results: The findings showed that interoperability challenges addressed using ICT tools, HL7 FHIR standards, SNOMED CT, LOINC, ABDM in an Indian context, HAPI FHIR Server using MPI, enabled by integrating with EMR, HIS, EHR System using HIE at micro, meso and macro levels. Conclusion: The interoperability has been discussed in terms of integrating different modules in the hospital settings, terms like e-prescribing, and patient portal. The micro, meso, and macro levels are discussed in terms of individual, organisational and policy. Further, the study can be focused on the usersof the EMR system at a micro level, the EMR system at a hospital setting at the meso level, and integrating the EMRs using the API, ABDM as EHR at the macro level.
Keywords: Interoperability, Types, Micro, Meso, Macro, EMR, EHR, ABDM

INTRODUCTION

"Interoperability refers to the ability of systems, processes, and organizations within an enterprise to effectively communicate, exchange data, and collaborate. It encompasses the seamless integration of diverse components, technologies, and standards to enable smooth interactions and shared functionality. Interoperability involves addressing conceptual, technological, and organizational barriers to achieve harmonious operation and compatibility across different levels and domains within the enterprise. It facilitates the efficient flow of information, services, and processes, leading to enhanced coordination, flexibility, and responsiveness in achieving business objectives"(Klausen et al., 2024). Interoperability in healthcare systems is crucial for efficient data exchange and improved patient outcomes. EMR and EHR systems often face interoperability challenges that can be categorized into micro (individual level), meso (organizational level), and macro (systemic level) levels. Interoperability comes in many forms, but it may be broadly divided into three categories: technical, semantic, and process interoperability. The capacity to transfer data from system A to system B regardless of the meaning of the data being exchanged is known as technical interoperability. mHealth and e-health enable technical interoperability. "eHealth" refers to the use of any kind of electronic equipment, such as desktop computers, in the delivery of healthcare, whereas "mHealth" refers to the use of mobile technology in the healthcare sector to assist clinical and public care(Mata et al., 2019).

Semantic interoperability is defined as the ability of the sender and receiver to understand data without ambiguity. It refers to the ability of two computer systems to be able to interpret and understand data that is exchanged.Standards developed to support semantic interoperability include HL7 and terminology models such as Systematic Nomenclature of Medicine-Clinical Terms (SNOMED-CT) and Logical Observation Identifiers Names and Codes (LOINC)(Mata et al., 2019). The HL7 v2.x and HL7 v3 standards were superseded by FHIR. The community has felt that HL7 v3 is too complicated and costly to utilise in reality, hence FHIR aims to create a more uniform and user-friendly standard for the interoperable transmission of medical data. FHIR is designed to foster interoperability by supporting the exchange of EHR between different systems and organisations, FHIR utilises HTTP, HTTPS, JSON, XML, and REST, modular API for seamless communication and data sharing (Klausen et al., 2024). Process interoperability refers to the coordination of business and work processes and common understanding between human beings across a network.Encounters between care providers and patients (e.g doctors and patients, patients and nurses, patient and therapists, nurses and doctors) to discuss diagnosis, treatment options, treatment progress, etc. is an important dimension to consider in healthcare interoperability; however, the process interoperability is often forgotten when designing systems to support healthcare delivery. A process framework should distinguish between the micro level (direct patient care), the meso level (management and evaluation of care providers), and the macro level (public health and regulatory processes). A performance management participation model identifies the processes that need to be managed at the micro, meso, and macro levels for clinical practice, and identifies the key actors and tasks relevant to performance management (Mata et al., 2019). Technical interoperability describes interoperability at a signal and protocol level; it describes how the data is captured and shared, such as "01001001," and several levels of interoperability were also determined based on the utilisation. Simple data sharing of information in the right format, such as interpreting binary data as an integer or text string, is made possible by structural interoperability. By using agreed-upon vocabulary, syntactic interoperability enables meaningful data interchange so that information is understood to be, for example, a patient's name or height. Consented vocabularies and application behaviour communication are necessary for semantic interoperability to identify whether an entry of data, such as "Sarah," as the patient's gender, is erroneous. Organization/Service Interoperability refers to the sharing of data between various systems or use cases(Guarrera et al., 2014). Synchronization of data, people, processes, and technology is needed to achieve seamless integration for better management of the system, and process. A clinical practice is a collection of processes that, together, support a particular type of healthcare for a particular community of patients. The complexity of the healthcare system means a single vendor cannot have the best solution for all operations and functionalities, even within a single hospital(Mata et al., 2019).

Definition – EMR, EPR, EHR : According to ISO/TR 14639-1:2012(en), an "electronic medical record" (EMR) is defined as an "electronic record of an individual in a physician's office or clinic, which is typically in one setting and is provider-centric", whereas an "electronic patient record" (EPR) is defined as an "electronic record of an individual in a hospital or health care facility, which is typically in one organization and is facility-centric". Given the previous two definitions, an electronic health record (EHR) is defined as follows: "Information relevant to the wellness, health and healthcare of an individual, in computer-processable form and represented according to a standardized information model, or the longitudinal electronic record of an individual that contains or virtually interline's to data in multiple EMRs and EPRs, which is to be shared and/or interoperable across healthcare settings and is patient-centric". Despite the great advances in electronic health records (EHRs) in the past 25 years, implementation and adoption challenges persist, and the benefits realized remain below expectations(Tsai et al., 2020).

ABDM: The Ayushman Bharat Digital Missionhas been launched by the Government of India to promote the digitization of healthcare and create an open interoperable digital health ecosystem for the country. It aims to do so by prescribing common health data standards, developing core modules such as the registry of health facilities, healthcare professionals etc required for interoperability; so that various digital health systems can be interoperable with each other by enabling seamless sharing of data across various healthcare providers who may be using different digital health systems.

Objectives: To do a literature review on interoperability challenges, when micro-level EMR system implementation is integrated at the macro level EHR system with ABDM.

Methods: A systematic review of studies on the interoperability challenges among the EMR system and EHR System at the micro, meso and macro levels was developed through the following stages: We limited the articles, reviews, and literature searches published from January 2014 to June 2024. The articles were downloaded from six different databases such as Google Scholar, Dimensions AI, ProQuest, PubMed, Taylor and Francis, and Mendeley. For finding duplicates and filtering based on the title, content used Mendeley Reference Manager, and for editing the document used Microsoft Word, for grammar checks used Grammarly.

Search Keywords: The keyword used for searching in the databases isinteroperability challenges, electronic medical records, electronic health records, EMR, EHR, standards, clinical terminology, SNOMED, ICD, LOINC, HL7,FHIR, DICOM, health information exchange, barriers, issues, integration, data sharing, data silos, legacy systems, privacy, security, middleware solutions, technical, policy, regulations, funding, incentives, cost, computer literacy, coordination, systems, processes, evaluation of technical ease, evaluation of functional ease, micro, macro and ABDM.

Study inclusion and exclusion criteria: Inclusion Criteria,papers on ABDM, interoperability challenges, micro-level, EMR, System implementation, integration, macro-level, EHR, the standards adopted for clinical terminology, disease code, imaging standards (SNOMED CT, ICD, LOINC, HL7 v2/FHIR, DICOM), legacy System, cost, policy, funding, standards, computer literacy, co-ordination and Infrastructure, privacy concerns of doctors, patients, staff and other stakeholders, systems and processes, evaluation of the technical and functional ease, published articles from 2014 to 2024(June,30), Open Access, were considered.

Exclusion criteria, Articles not in English, studies not focused on interoperability, EMR, EHR, Standards, theoretical papers, other micro/macro, electronic magnetic radiations, abbreviations not relevant to EMR, published previously before 2014.

Results: A total of 1042 papers were identified by searching six bibliographic databases. The 151 duplicated publications were excluded. After the screening, the title, and abstract of the retrieved documents, 789 irrelevant papers were excluded and 102 articles were considered for full-text evaluation, from which 36 papers were selected for the review. The flow of the process of study selection is shown in figure-1 PRISMA – Flow Chart.

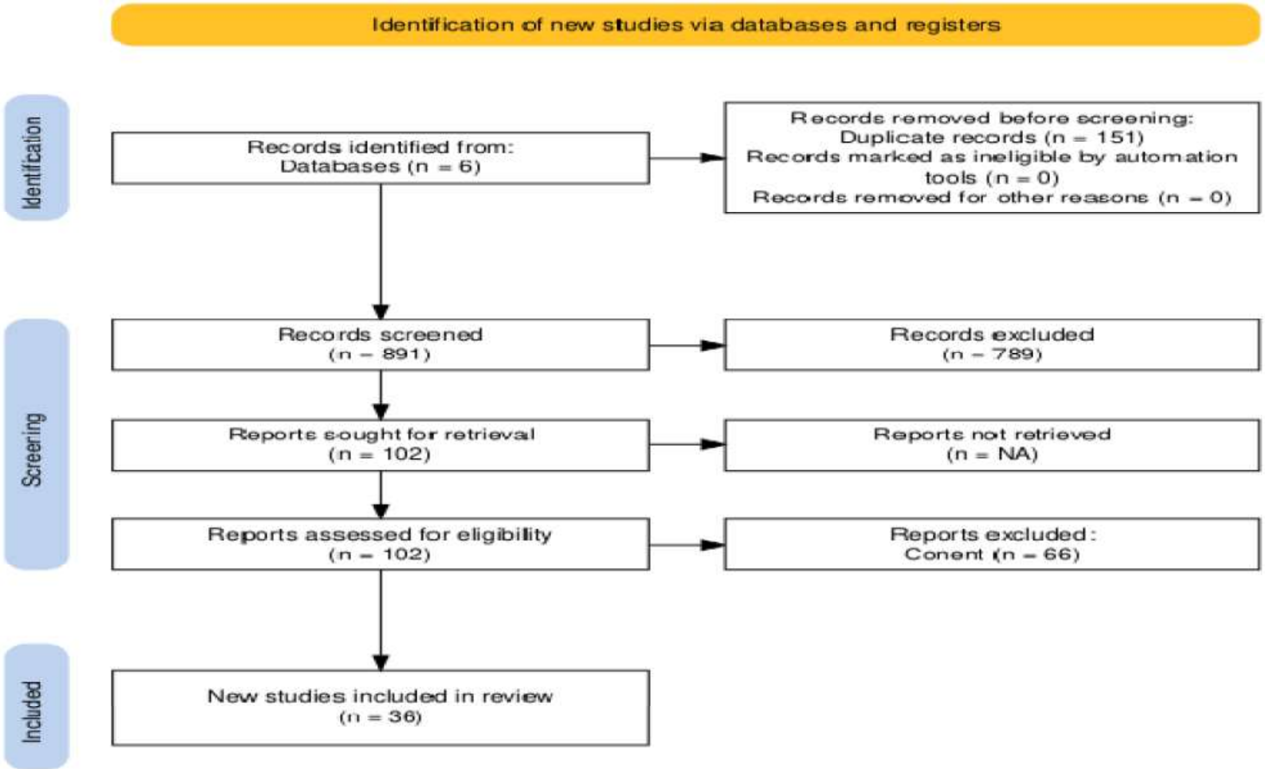

Figure 1 PRISMA – Flow Chart(Haddaway, 2022)

Review Findings

Table1: Summary of review findings

Study	Authors, Study Year	Country	Is it similar to ABDM	Level	Type of Interoperability	Interoperability challenges	EMR / EHR, proposed solution	Results
1.	(Klausen et al., 2024)	Germany	Yes	Micro - Patients Doctors, Meso- German Healthcare System, Macro-E-Certificate	Semantic	Custom extensions, manual data entry and integration of an identity provider.	The study assessed the feasibility of using the HL7 FHIR standard, for implementing a digital vaccination pass management and monitoring system, aimed to offer convenience and improved efficiency, by promoting interoperability among the users. The prototype was developed using React, Quarkus, and Keycloak.	Access to immunisation records, personalised recommendations, streamlined management, using FHIR R4 enhance efficiency, data accessibility and accuracy in the vaccination process across settings.
2.	(Mata et al., 2019)	Canada	The study discusses global health information exchange systems, which are conceptually similar to the objectives of ABDM	Micro-Level: Within single healthcare organizations Meso-Level: Between different healthcare organizations Macro-Level: At the national or international level.	Semantic and Syntactic	Data Standardization: Lack of standardized formats for data exchange. Technical Integration: Difficulty in integrating various legacy systems. Privacy and Security: Concerns about safeguarding sensitive health data during exchange. Cost and Funding: High costs associated with implementing interoperable systems.	The framework for clinical practice performance management maps goals and indicators to the growing need for accountability and transparency as well as to promote improvements in the quality of care. It also identifies the processes that must be managed at the micro, meso, and macro levels, as well as the key actors and tasks using the performance management model.	Illustrated how the framework may be used to explain why an app was stopped being used after two years and how it is a better approach than the one used before. The study found that countries that adopted standardized frameworks for interoperability, such as those outlined by HL7 and FHIR, achieved better integration of health information systems. It also highlighted the need for continuous updates to technology and policies to keep pace with evolving healthcare needs and technologies.
3.	(Rinty et al., 2022)	Bangladesh	Yes	Macro - Developing country context, with a focus on rural and urban healthcare systems	Semantic - Distributed, loose coupling	Challenges of interoperability among e-Record systems included: (i) A lack of e-Record system law and governance. (ii) A lack of ICT support. (iii) Insufficient support funds. (iv) A lack of expertise to use e-Record systems. (v) Non-uniform unique patient identifiers (UPI). (vi) Non-enforcement of	To attain interoperability among e-health systems for connecting each other and sharing data in a secure way involving efficient health data management. Data interchange standards, such as the HL7 standard, as well as digital imaging and communications in medicine (DICOM), can help with interoperability. Proposes a distributed	A loosely coupled low-cost distributed system enables interoperability in healthcare structures and is used to create flexible architecture. The proposed system provides a low-cost, effective service for developing countries,

						interoperability standard Fragmented health data, lack of motivation and adaptation to EHR systems, absence of backup plans in centralized systems, security threats, and need for data recovery mechanisms.	EHR system with loose coupling, using Health Level 7 (HL7) standards and Message Passing Interface (MPI) for regular backups and secure data handling	enables interoperability, and offers significant benefits in digital storage and access to patient health records.
4.	(Pattanaik et al., 2024)	India	Yes, focuses on the adoption of a digital health records system linked to the Aadhar Card, aimed at improving the effectiveness of the health system in India and contributing to green practices.	Macro Level: The study addresses the national implementation and policy-level aspects of the Electronic Health Information Exchange System.	Technical and Semantic	Security concerns related to personal health information. Privacy and confidentiality issues. Trust and acceptance by the public. Regulatory compliance and alignment with Sustainable Development Goals (SDGs).	Validates the adoption behaviour using the APCO (Antecedent, Privacy-Concern, and Outcomes) model and the Theory of Planned Behaviour (TPB). It emphasizes the need for robust privacy and security measures to build public trust and ensure successful adoption.	A positive impact on the intention of citizens to use the EHIE system for exchanging health information. Highlights the importance of addressing privacy concerns and fostering trust to enhance the adoption of the EHIE system The structural equation modelling (PL-SEM) technique validated the hypotheses, showing that the EHIE system positively influences citizens' adoption intentions.
5.	(Sharma et al., 2023)	India	Yes	National	technological data interoperability through building blocks like ABHA, HFR, HPR, and HCX.	Privacy concerns, integration with the legacy or existing systems, acceptance among stakeholders, and ensuring security and consent management.	The federated architecture was implemented to manage health data, Health Information Exchange and Consent Manager for secure data sharing.	Significant adoption with over 35 crore ABHA accounts, nearly 25 crore health records linked, and thousands of professional and facility registries created. The initiative has also led to increased reliability, affordability, and innovation in healthcare through digital means.
6.	(De et al., 2021)	United States	No	Micro, Meso and Macro Concepts	Semantic (FHIR)	Patient portals tethered to the EHR system, through web platforms.	To develop a data model for patient secure messages based on the FHIR standards to identify and extract significant information	A 3-level hierarchical structure of health system concepts including 3 macro, 28 meso and 85 micro.

7.	(Guarrera et al., 2014)	New York, USA	No	Meso	Techno-Centric Technical	The system's specific technological capabilities and their impact on clinical workflow .	A new, seven-level framework is presented to characterise the impact of varying levels of interoperability on the users' work based on qualitative data gathered in a field study of the use of health information exchange in 12 ambulatory practices. The existing interoperability frameworks are synthesised from select interoperability frameworks in the literature about both medical and non-medical systems.	Level 0 to Level 6 are interoperable systems in which data elements from other institutions are seamlessly and computationally formattedly integrated into the patient's record. The lowest level describes paper-based tasks completed without access to electronic information from other institutions.
8.	(Samudyatha et al., 2023)	India	Yes	Micro, Meso, Macro	Technical, Semantic, Syntactic	To develop an expert consensus on how Community Medicine (Preventive and Social Medicine) can be integrated into ABDM	Helps to expand the goals of India's digital health program, which has community medicine as a cornerstone.	"Participants envisaged improved accessibility, affordability, and quality of care" due to ABDM. However, awareness generation, reaching out to marginalized populations, human resource constraints, financial sustainability, and data security issues were anticipated challenges.
9.	(Gøeg et al., 2014)	Denmark, Sweden	Yes	Micro, Meso, Macro	Semantic – SNOMED CT	Models and terminology make achieving semantic interoperability	A complete physical examination required the inclusion of exact matches and terminology similarities	The analysis suggests that there were both similarities and differences in physical examination templates, and the size of the templates varied from 18 to 49 fields.
10.	(Li et al., 2021)	United Kingdom	Yes	Not mentioned	Generalised as interoperable – not specific to any type	Examine the effects of EHR interoperability on patient safety or other aspects of high-income healthcare settings' quality of care.	With the growing tendency for patient involvement and stewardship of their electronic clinical data, analyse patient views and highlight both the positive aspects and negatives of interoperable EHR interventions.	The results were divided into six common outcome measure categories: cost savings, productivity, data accuracy and mistakes, drug safety, patient safety incidents, and care efficacy. EHR interoperability improved patient safety,

								decreased expenses, and improved drug safety. There have been mixed improvements to the clinical workflow and time-saving.
11.	(Jayathissa& Hewapathrana, 2024)	SriLanka	The document does not directly mention ABDM (Ayushman Bharat Digital Mission). However, the efforts to enhance interoperability and implement a Master Patient Index (MPI) and a Health Information Management System share similarities with the objectives of ABDM.	Primary Care Health Information Systems	Semantic - FHIR	Lack of interaction between HIS, Non-interoperable primary HIS, Need a unified system to share records among primary and secondary care.	Centralise patient information, including medical history, treatment plan, and diagnostic data, Implementation of HAPI-FHIR Server, to achieve interoperability, use of Master Patient Index(MPI) for integration, Strengthening primary healthcare through the Primary Care System Strengthening Project (PSSP)	Enhanced data accessibility and coordinated care among healthcare providers, Improved appointment scheduling and workflow management, Facilitated comprehensive patient care through seamless data exchange, Contribution to public health initiatives by supporting surveillance and reporting, Enhanced decision-making with decision support systems.
12.	(Catan et al., 2015)	Israel and Portugal	Implementing national-level health information technology policies	Micro (users and physicians), Meso (healthcare organization), Macro (government)	National Health Information Systems, eHealth, and mHealth	Legal issues (privacy and security), social problems (digital divide), government direction and priorities, bureaucracy, innovation vs. interoperability	Implementation and comparison of EMR systems, National strategies for eHealth and mHealth, government-regulated interoperability	ICT has increased access to information, empowering patients and changing physician behaviour; government involvement is crucial for nationwide interoperability, though it may slow innovation
13.	(Kumar Sharma et al., 2024)	India	Yes, in terms of using technology to enhance healthcare through digital health initiatives	National (impact on the healthcare system), with a focus on individual health monitoring	Integration of digital wearables with clinical terminologies (SNOMED CT, LOINC)	Ensuring accurate coding, documentation, and analysis; managing data from diverse wearable devices; maintaining consistent data standards	Focus on enhancing interoperability between wearables and EHR systems, Integrating digital wearables with standardized clinical terminology to ensure seamless data exchange and accurate health data interpretation.	The integration facilitates real-time patient data analysis, improves clinical decision-making, promotes personalized care, and supports the management of non-communicable diseases (NCDs)
14.	(Mirza et al., 2024)	India	Yes	Meso, macro	Technical, syntactic and functional	Bridging data gaps across the treatment chain, ensuring the secure and efficient transfer of patient data through multiple levels	Use of HMIS to register patients under ABDM, generation of ABHA numbers for online medical records, and central gateway control	Better load balancing of healthcare services, improved tracking and

						of care	room for managing patient distribution and referrals.	management of patient pathways, enhanced integration and coordination across different healthcare levels.
15.	(Torab-Miandoab et al., 2023)	Not explicitly mentioned	Discuss various levels of interoperability, which is similar to ABDM's goal.	Macro	Technical, Syntactic, Pragmatic, Dynamic, Conceptual, Structural, Functional and Semantic	Regulatory compliance, Security Concerns, Complexity and variability of software solutions, Need for seamless data sharing while protecting patient privacy.	Use of HL7 FHIR for transport standards, CDA for content standards, SNOMED CT for a common clinical language	Improved clinical decision-making, reduced data duplication, and manual data entry, enhanced patient care coordination and reduced readmissions.
16.	(Kierkegaard, 2015)	Denmark	Not Specified	Regional and National (Macro)	Technical, Organisational and Legal	Technical incompatibilities, organisational resistance, legal and regulatory issues, Data privacy and security concerns.	Clear and mandatory guidelines for electronic patient records. Standardized protocols and data formats. Legal frameworks to support data sharing and interoperability.	The Federal Ministry of Health took over the responsibility to develop interoperability guidelines. Commissioned Federal Association of Statutory Health Insurance Physicians to establish standards
17.	(Mugabe Nzarama et al., 2024)	Rwanda	Not directly mentioned	National - Macro	Health Information Exchange guidelines and standards	Environment compliance with HIE guidelines, the necessity of clear strategies for implementing interoperable EHR systems	Challenges and solutions for interoperability	The interoperable EHR systems can supplement existing HIE guidelines and standards.
18.	(Ndlovu & Scott, n.d.)	Botswana	Not Specified	National-Macro	Technical and Organisational	Lack of interoperability between mHealth applications and eRecord systems. Different proprietary eRecord systems. Fragmented care delivery. Duplication of effort and unnecessary healthcare expenditure.	Development of an interoperability platform. Adoption of global interoperability standards and APIs. Cloud-based infrastructure to support mHealth applications. Integration with diverse eRecord systems in both public and private sectors.	Identified the need for interoperability between mHealth applications and eRecord systems. Guided enhancing the national eHealth strategy
19.	(Stegemann & Gersch, 2019)	Germany	Not Specified	National - Macro	Technical, Economic	Financial constraints, technical complexities and lack of standardized guidelines	Federal Ministry of Health's initiative to develop clear and mandatory guidelines. Commissioned Federal Association of Statutory Health Insurance Physicians to create interoperability standards.	Development of electronic patient record guidelines as a core application. Ongoing debate about the feasibility and implementation of interoperability
20.	(Fennelly et al., 2024)	Ireland	Yes	Not Specified	Not Specified, Generalised	Patient portals and electronic health records	To identify the key requirements and challenges to interoperability between patient portals and electronic health records	few offered patients access to their entire healthcare record across multiple sites and several different

								functionalities were available. Key interoperability requirements and challenges identified were: Data Sharing Incentives & Supports; Heterogenous Organisations & Information Systems; Data Storage & Management; Available Information & Functionalities; Data Formats & Standards; Identification of Individuals; User Access, Control & Consent; and Security & Privacy.
21.	(Heeney et al., 2023)	UK, US, Norway and Netherlands	Partial	Micro, Meso and Macro	Systemic	ePrescribing in hospitals through the interopera bility of systems and processes	Achieving interoperability is key in making ePrescribing systems both safe and useable. Data resources exist at macro, meso and micro levels, as do the governance interventions necessary to achieve system interoperability.	Thematic analysis identified 4 main drivers for increasing ePrescribing systems interoperability: (1) improving patient safety (2) improving integration & continuity of care (3) optimising care pathways and providing tailored decision support to meet local and contextualised care priorities and (4) to facilitate the interoperability of complete patient care services across several contexts and places.
22.	(Li et al., 2023)	England	Yes	Not Specified	Foundational, Technical, Semantic,	Daily obstacles related to the acquisition, implementation, upkeep, and utilisation of interoperable EHR systems, as seen by healthcare administrators, including chief clinical information officers.	The opinions of CCIOs regarding the EHR interoperability in the NHS at the moment, how it affects patient safety, what obstacles they see in the way of enhancing interoperability, and what they think the future holds for EHR development in the NHS.	Due to poor EHR interoperability, data fragmentation resulted from the inability to swiftly access and transfer data into a single source. Uncertainty in health status reports has a negative impact on patient

								safety because it might generate defensive behaviour, ineffective care coordination, and effort duplication. In addition to institutional, data management, and budgetary concerns, there are system usability issues.
23.	(Walker et al., 2023)	US	Yes	Not specified, specifically, but discusses Micro, Meso and Macro	Technological, Organisational, Environment	To determine the possibilities and obstacles that currently exist for improving interoperability among stakeholders	Regional health information exchange networks, primary care physicians, behavioural health practitioners, and directors of acute care and children's hospitals. Key informant viewpoints on the adoption of electronic health records, the alignment of organisational strategy with public policy, the difficulties in implementing interoperability, and the potential for health information technology were the main topics of the interviews.	Themes concerning opportunities and obstacles to interoperability that fit into the technological (implementation difficulties, inconsistencies in stakeholders' interoperability capacities, and chances to use new technology and incorporate social determinants of health data), organisational (interoperability facilitators and strategic alignment of participation in value-based payment programs with interoperability), and environmental (policy) domains
24.	(Ahmadi et al., 2014)	Malaysia	The document does not explicitly mention ABDM, but it discusses the adoption and integration of EMR in Malaysian public hospitals, which aligns with the objectives of digital health missions like ABDM.	Macro	HIS (Health Information System) standards Socio-political-economic trends	Low adoption rates despite clear benefits Duplication of information due to non-integrated data systems Standardization issues Legal and policy governance Funding incentives	The paper proposes the use of the Fuzzy Analytic Hierarchy Process (F-AHP) to prioritize the factors affecting EMR adoption. Standardized data, economic trends, and political trends are emphasized as crucial sub-factors for successful EMR adoption.	The most important factors for EMR adoption are socio-political-economic trends and HIS standards. Important sub-factors include economic trends, standardized data, and political trends. The study highlights the need for focused efforts on these macro-level factors to improve EMR adoption rates

								among physicians in public hospitals in Malaysia.
25.	(Randhawa, 2019)	Various countries	The study reviews various articles discussing the quality and experience benefits of EHR adoption, which can be aligned with digital health initiatives similar to ABDM	micro, meso, and macro	The study discusses interoperability in the context of EHR adoption, emphasizing the quality and experience benefits.	Challenges include ensuring data quality, integrating with existing systems, and maintaining data privacy and security.	Adoption and effective use of EHR systems to realize quality and experience benefits.	EHR adoption and use lead to significant improvements in care quality, patient safety, and overall healthcare experience, despite facing interoperability challenges
26.	(Ojeda-Carreño et al., 2017)	Various countries	Yes – Exploratory study	Not Specified	Semantic, Syntactic	The relevant Medical Standards, vocabularies and terminologies for tackling interoperability problems.	The study outcome suggests to use of SNOMED CT, LOINC, ICDx, and OpenEHR to improve interoperability.	The interoperability recommended through the exploratory study, suggests to use of the vocabularies and terminologies, to achieve semantic and syntactic.
27.	(Zhang et al., 2019)	US	Yes	Not specified	Semantic, Syntactic	Clinical lab tests integrating with EHR using Semantic for phenotyping and biomarker	LOINC, SMART on FHIR proposed to integrate with EHR and convert the tests using HPO (Human Phenotype Ontology)	Easily accessible laboratory tests in the EHR that may be utilised again for deep phenotyping and that combine various tests with similar medical interpretations for association studies by taking advantage of the hierarchical structure of HPO
28.	(Palojoki et al., 2024)	Various Countries	Yes	Not specified	Semantic	Semantic interoperability between the EHR system and other modules.	The possible standards, goals and benefits, and elements available for integrating EHR using Semantic interoperability.	To create interoperability, data models, ontologies, terminologies, classifications, and standards were used. Data availability to the clinicians, quality of care, enhanced use and reuse of data
29.	(Mandel et al., 2016)	USA	Not specifically, mentioned, but focuses	Micro, Meso and Macro	Data and Functional	Semantic consistency, vendor adoption, Complexity of standards, Technical obstacles	EHR to support interoperable, using SMART on FHIR, Profiles and Open Standards	Feasibility demonstration by successful adoption of SMART on FHIR, Vendor and Developer feedback was positive.

30.	(Perugu, MBA et al., 2023)	United States	Not Specified	Micro (Point of care), meso (Intra-facility) and Macro(inter-facility)	Data exchange and communication across settings	Varying clinical terminologies, technical specifications, functionalities of EHR, Redundancy and difficulty in accessing data, Scalability issues, and Different EHR platforms cause delays.	EMR and EHR are considered, by integrating to enhance interoperability, implementing standardized communication protocols, and middleware architectures, utilising data management technologies, engaging stakeholders for feedback during the implementation process	IHIE (Indiana Health Information Exchange) implemented advanced interoperability, reducing redundancy and improving data quality.
31.	(Pine, 2019)	United States	Yes	Micro, meso and macro	Technical and Semantic	Technical Challenges: Diverse EHR platforms and non-standardized data formats lead to difficulties in data exchange. Semantic Challenges: Variations in clinical terminologies and coding constructs between systems cause discrepancies and hinder meaningful data exchange. Organizational Challenges: Different healthcare entities have unique needs and existing infrastructures, making it challenging to implement a one-size-fits-all solution.	Middleware Architectures: The study proposes the use of middleware architectures to facilitate interoperability by standardizing and cleaning data from diverse sources. National Frameworks: The implementation of TEFCA (Trusted Exchange Framework and Common Agreement) is suggested to provide a common ground for data sharing across the US healthcare system.	Implementation of Standards: Successful adoption of standards like FHIR and C-CDA at various levels of healthcare to improve data exchange. Reduction of Redundant Processes: Intermediate platforms and standardized frameworks have reduced redundant processes and improved data accessibility. Improved Data Quality: Implementation of solutions like Medflow's image management system has enhanced the quality and accessibility of medical images and data.
32.	(Modi & Feldman, 2022)	United States	Relevant, as it discusses the value and impact of EHRs, which is similar to ABDM's goals of integrating digital health records across India	National and Regional	Syntactic, Semantic	Technical barriers Data standardization issues, Lack of uniform adoption across facilities Difficulties in integrating diverse systems	Various solutions are proposed, such as implementing standardized protocols, enhancing data-sharing frameworks, improving user training, and adopting comprehensive EHR systems to streamline documentation and improve clinical outcomes. Adoption of EHRs, use of health information exchanges (HIEs), and standardization of health IT systems.	Improved clinical quality measures, financial performance, patient outcomes, and operational efficiency. Enhanced patient safety, reduced medical errors, better quality of care, and financial benefits like increased revenue and improved cost efficiency
33.	(Fennelly et al., 2021)	Ireland, Northern Ireland, England	Not explicitly stated, but it discusses the use of standardized terminologies,	National	Semantic Interoperability - Standardized terminologies (STs) like	The use of multiple STs complicates data aggregation and generalization. Variability in healthcare settings and patient	Discusses the integration of STs within EHRs to improve documentation quality, interoperability, and patient care.	STs have the potential to improve communication, quality of care, and

			which is relevant to interoperability.		NANDA-I, NIC, NOC, Omaha System, SNOMED-CT, LOINC, and others	cohorts affects the impact. Usability issues like time efficiency, system response time, and user perceptions	Employment of standardized terminologies to enhance communication, quality of care, interoperability, and knowledge generation in clinical practice.	interoperability. The impact is influenced by healthcare settings, patient cohorts, nursing experience, and EHR usability. Positive outcomes are dependent on the specific term, patient presentation, condition, and clinical setting
34.	(Shen et al., 2019)	Not mentioned	Relevant, as it discusses health information exchange which is part of interoperability	Not specified	Syntactic and Semantic	Patient privacy concerns Data security Consent Management	Addressing privacy concerns through robust consent management and security measures	Improved patient trust and willingness to participate in health information exchanges(
35.	(Ryan et al., 2017)	Likely UK (based on the affiliations of Dr. Dermot Ryan)	The focus on electronic medical records and improving healthcare efficiencies aligns with ABDM's objectives, although the specific context may differ.	Primarily macro-level, focusing on system-wide efficiencies and risk management	Technical and Semantic	Integrating diverse data sources (EMRs, biomarkers).Ensuring accurate and comprehensive data capture	Central to the study, focusing on the use of EMRs for managing healthcare data. Utilizing EMRs and biomarkers to track patient data and manage risks. Developing systems to integrate and analyze these data sources	Improved management of patient risk. Enhanced resource efficiencies in healthcare settings
36.	(Watson et al., 2021)	Canada	Not explicitly stated, but it involves digitizing healthcare processes and integrating patient data, similar to ABDM's goals.	Micro: Individual patient level Meso: Clinic level Macro: Program Level	Technical and Semantic	Lack of direct patient entry into EMR. Limited display and reporting capabilities within existing EMR systems	Implemented within the provincial EMR system to track and integrate PROMs data. A hybrid data-entry process where patients complete paper-based PROMs and clinicians input data into the EMR. Development of digital dashboards for various levels (micro, meso, macro) to track and utilize PROMs data.	Enhanced patient-clinician communication.Improved symptom management. Over 60,000 unique patients and 300,000 unique screening events were captured. Use of PROMs data for targeted care, clinic staffing, and provincial program planning

Discussion: Overview of Interoperability in EMR/EHR Systems

Interoperability within Electronic Medical Records (EMR) and Electronic Health Records (EHR) systems is pivotal for achieving integrated, high-quality healthcare delivery. Despite numerous advancements, several challenges persist, impeding seamless data exchange and utilization across different healthcare entities.

Current State of Interoperability

The implementation of interoperability in healthcare systems varies globally, with significant strides made in some regions while others lag due to infrastructural, economic, and regulatory barriers. The concept of interoperability encompasses multiple dimensions: technical, semantic, syntactic, and organizational. Each of these dimensions must be addressed cohesively to realize fully interoperable health information systems.

Technical Interoperability, involves the seamless exchange of data between different systems using standard protocols and technologies. This includes hardware, software, and network components that must be compatible to enable effective communication. Key challenges include the integration of legacy systems, variability in technology adoption, and the rapid evolution of interoperability standards.

Proposed Solutions:
- Adoption of widely recognized standards such as HL7 and FHIR.
- Implementation of cloud-based platforms to enhance scalability and connectivity.
- Development of APIs to facilitate data exchange between disparate systems.

Semantic Interoperability, ensures that the meaning of exchanged information is preserved and consistently understood across different systems. This is achieved through the use of standardized terminologies and coding systems, such as SNOMED CT and LOINC.

Challenges:
- Variability in the adoption of standardized medical terminologies.
- Differences in coding practices and data interpretation across healthcare providers.

Proposed Solutions:
- Comprehensive adoption of international standards.
- Regular training for healthcare professionals to ensure consistent use of terminologies.
- Continuous updates and harmonization of coding systems.

Syntactic Interoperability, deals with the structure or format of the data being exchanged, ensuring that data can be correctly parsed and interpreted by receiving systems. Standardized data formats such as XML and JSON play a crucial role here.

Challenges:
- Ensuring adherence to standardized data structures across all systems.
- Managing the complexity of data formats and evolving standards.

Proposed Solutions:
- Enforcement of standard data formats and structures.
- Development of tools and middleware to facilitate data conversion and integration.

Organizational Interoperability focuses on aligning business processes, policies, and procedures to support effective data sharing and collaboration among healthcare entities. This involves fostering trust, establishing governance frameworks, and ensuring regulatory compliance.

Challenges:
- Diverse organizational cultures and priorities.
- Resistance to change and adoption of new processes.
- Ensuring data privacy and security while facilitating data sharing.

Proposed Solutions:
- Establishment of shared governance structures.
- Development of clear data-sharing agreements and policies.
- Continuous stakeholder engagement and change management initiatives.

Privacy and Security Concerns

Ensuring the privacy and security of patient data remains a critical concern. Robust measures must be in place to protect sensitive information from breaches and unauthorized access.

Challenges:
- Balancing data accessibility with stringent privacy requirements.
- Addressing the risks associated with data breaches and cyber threats.
- Compliance with regional and international privacy regulations.

Proposed Solutions:
- Implementation of advanced encryption techniques and access controls.
- Regular security audits and risk assessments.
- Comprehensive training for healthcare staff on data privacy and security protocols.

Economic Constraints

The financial burden associated with implementing and maintaining interoperable systems is substantial, particularly for smaller healthcare providers and developing countries. Economic constraints can hinder the adoption of necessary technologies and standards.

Proposed Solutions:
- Securing funding from government and private sectors.
- Leveraging cost-effective technologies and open-source solutions.
- Collaborative efforts to share resources and infrastructure.

Results and Impact

The successful implementation of interoperable EMR/EHR systems has profound implications for healthcare delivery. Key benefits include:

1. **Improved Patient Care**:
   - Enhanced care coordination and clinical decision-making.
   - Reduction in medical errors and duplication of tests.

2. **Operational Efficiency**:
   - Streamlined workflows and reduced administrative burdens.
   - Better resource allocation and cost savings.
3. **Patient Engagement**:
   - Empowering patients with access to their health information.
   - Improved patient satisfaction and engagement in their care.
4. **Public Health**:
   - Enhanced public health surveillance and disease management.
   - Better data for research and policy-making.
5. **Trust and Compliance**:
   - Increased trust among patients and stakeholders.
   - Compliance with regulatory requirements and standards.

Conclusion

Interoperability in EMR/EHR systems is a multifaceted challenge requiring coordinated efforts across technical, semantic, syntactic, and organizational domains. Addressing these challenges through standardized protocols, robust security measures, and collaborative governance frameworks will pave the way for integrated, high-quality healthcare systems. The ongoing efforts and proposed solutions discussed in this study highlight the path forward for achieving comprehensive interoperability, ultimately leading to improved healthcare outcomes and operational efficiencies.

Abbreviations

ABDM - Ayushman Digital Health Mission
ABHA – Ayushman Bharat Health Account
APCO – Antecedent, Privacy-Concern and Outcomes
API - Application Programming Interface
C-CDA - Consolidated Clinical Document Architecture
CCIO – Chief Clinical Information Officer
CDA – Clinical Document Architecture
DICOM – Digital Imaging and Communications in Medicine
EHR - Electronic Health Record
EMR - Electronic Medical Record
EPR – Electronic Patient Record
F-AHP – Fuzzy Analytic Hierarchy Process
FHIR -nFast Healthcare Interoperability Resources
HCX – Health Claims Exchange
HFR – Health Facility Registry
HIE – Health Information Exchange
HIS – Health/ Hospital Information System
HL7 – Health Level 7
HMIS – Health / Hospital Management Information System
HPR – Healthcare Professionals Registry
HTTP - Hypertext Transfer Protocol
HTTPS - Hypertext Transfer Protocol Secure
ICT – Information, Communication and Technology
IHIE – Indiana Health Information Exchange
JSON - JavaScript Object Notation
LOINC – Logical Observation Identifiers, Names and Codes
MPI – Master Patient Index
NANDA-I - North American Nursing Diagnosis International
NCD – Non-Communicable disease
NHS – National Health Stack
NIC - Nursing Interventions Classification
NOC - Nursing Outcomes Classification
PL – SEM – Partial Least Squares Structural Modelling
PRISMA – Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROMs - Patient-reported outcome measures
PSSP – Primary Care System Strengthening Project
REST - Representational State Transfer
SDG – Sustainable Development Goals
SNOMED CT – Systematic Nomenclature of Medicine – Clinical Terms
ST - Standardised Terminologies
TEFCA - Trusted Exchange Framework and Common Agreement
TPB – Theory of Planned Behaviour

UPI – Unique patient indentifiers
XML - Extensible Markup Language

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