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FUNCTIONAL AND COMMUNICATIVE INTEROPERABILITY IN EUROPEAN HEALTHCARE SYSTEMS: A COMPARATIVE OVERVIEW OF HL7 FHIR, openEHR, AND OMOP IN ESTONIA, DENMARK, FINLAND, AND GERMANY

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Abstract: *This study investigates the extent to which the HL7 FHIR[1], openEHR[2], and OMOP[3] medical data models contribute to operational interoperability in European clinical care networks. Using a methodical document analysis, four countries – Estonia, Denmark, Finland, and Germany – are compared according to defined analysis parameters. The results show clear differences in the degree of integration, institutional control, and IT integration. Beyond technical data transfer, the study defines conceptually functional system interoperability as an information process of communication and organisation embedded in governance structures, institutional coordination, and regulated information flows. While Estonia and Finland have hierarchically organized IT systems with a high degree of integration, Germany has decentralized structures. The study shows that the effectiveness of interoperable standards depends not only on their technical specifications but also on their regulatory, administrative, and systemic integration. This has direct relevance for the development of evidence-based, intelligent care systems within the European Health Data Space. The paper shows that operational interoperability should be viewed as a structural concept that requires multidisciplinary coordination strategies. The results can, in principle, support future interoperability projects – especially in the country-specific adaptation of electronic care platforms.*
Keywords: *EU health systems; functional interoperability; data standardisation; communication, comparative analysis*

INTRODUCTION

Digital modernisation in European healthcare is progressing, but the structured use of health information continues to be hampered by heterogeneous infrastructures, isolated sector structures, and fragmented interfaces (OECD 2023, p. 14; EHDS 2023). National divergences in data accessibility, semantic terminology, and institutional implementation not only impair service provision but also scientific research and transnational cooperation (TEHDAS 2023, p. 11)[4].

Initiatives such as the European Health Data Space (EHDS 2023) and recommendations from TEHDAS and the OECD therefore call for interchangeable data models that allow for the clearly defined, legally compliant, and technically integrable use of health-related information (OECD 2023, pp. 9–12; TEHDAS 2023, pp. 7–9)[5]. The primary focus is on functional interoperability – i.e., the ability not only to transfer data but also to validate it adequately and apply it effectively in new use cases (cf. ISO/TS 22600-1:2014, p. 6; Kapitan et al. 2025, p. 28)[6]. From the perspective of information science, operational interoperability accordingly denotes not merely a technical capability, but a communicative and organisational information process shaped by governance frameworks, institutionally structured coordination, and regulated data flows.

Considering the challenges faced by the European healthcare system, a comparative study is needed to assess the functional interoperability of current data models. This implies the following core question of the study:

To what extent do the HL7 FHIR, openEHR, and OMOP health information models contribute to the consolidation of functional interoperability within European health systems, and which technological and institutional framework factors reinforce or impede their practical implementation?

Three analytical sub-questions are examined to discuss this overarching question:

To what extent can HL7 FHIR, openEHR, and OMOP be used to achieve the technical and syntactic interoperability necessary for functional data use in healthcare and research?

Which management and implementation strategies (e.g,. X-Road, Findata, Sundhed.dk) facilitate or block functional interoperability between academic research units and healthcare systems?

To what extent do Estonia, Denmark, and Finland differ in their practical use of functional interoperability, and what insights can be derived from this for Germany?

The sectoral division of European healthcare structures outlined in the introduction and the institutional disparities in data availability (OECD 2023, p. 14; TEHDAS 2023, p. 11) show that interoperability is not exclusively a technical issue, but rather a multifaceted conceptual problem. The following theoretical concepts define key terms, differentiate between levels of interoperability, and systematise the HL7 FHIR, openEHR, and OMOP data models used based on existing classification frameworks. In doing so, they generate a methodological connection point for comparative analysis.

Definition of interoperability

Interoperability determines the functionality of various systems to realise information flows, interpret them accurately, and reuse them for specific purposes. ISO/TS 22600-1[4] classifies technical, syntactic, and semantic-structural interoperability (ISO, 2014, pp. 2–3). Of particular importance are operational interoperability, semantic congruence, and the process-related usability of data across systems (Kapitan, Zimmermann & Stumpf, 2025, p. 28).

Functional versus semantic interoperability

According to the WHO (2016, p. 23), semantic interoperability is based on operational interoperability and aims to achieve clear, algorithmically supported interoperability of encrypted data. Benson and Grieve (2016, pp. 31–34) describe functional interoperability as the transfer of meaning between platforms, whereas semantic interoperability refers to the standardized mapping of multidimensional medical knowledge content. The IHE framework[5] provides practical guidelines for integrating both levels of interoperability within feasible application structures (IHE, 2021, pp. 10–12).

Health data architectures as mechanisms of system compatibility

FHIR, openEHR, and OMOP are considered structural models of interoperability, essential for the methodical integration of health data. The openEHR structural concept is based on a two-stage framework that maps clinical expertise onto standardized data archetypes, thus enabling semantic coherence (Beale 2002, pp. 1–3).

OMOP implements a relational data architecture based on standardized technical terminology to ensure the reproducibility of medical data analyses (Hripcsak et al., 2015, pp. 668–669). FHIR aggregates interoperable information components using REST-compliant API modules and has thus established itself as a globally recognized reference standard for ensuring interoperable health data (HL7 2021, pp. 4–5).

Institutional and legal framework conditions

Governance-related structural requirements shape the establishment of cross-system information systems. In this context, such governance-related arrangements may be interpreted as instruments of information governance that control communicative coordination, access regulation, and the responsible management of health-associated information across organisational boundaries. The European Health Data operationalises specifications for semantic standards, legally defined access options, and data portability (European Commission 2023, pp. 5–7). The OECD (2023, pp. 9–12) emphasises the importance of transparent control mechanisms and intersectoral coordination. These legislative framework requirements create the regulatory framework for the conceptual implementation of data structure models.

RESEARCH METHODOLOGY

Reference to the methodological framework

The conceptually sound terminologies, hierarchies of system interoperability, and reference frameworks define the basic conceptual framework for the methodological comparative study in Chapter 4. The decision to select HL7 FHIR, openEHR, and OMOP was based on their representativeness, degree of standardisation, and organisational consolidation within digital health initiatives.

This work is aimed at qualitative-analytical research to compare the functional interoperability of health information systems in selected European countries. A qualitative analysis methodology was chosen because it enables the contextual evaluation of complex institutional, systemic, and regulatory frameworks based on documents (WHO 2016, p. 25; OECD 2023, p. 12).

The methodology of this study aims to provide a structured answer to each of the research questions formulated in the introduction. To this end, the HL7 FHIR, openEHR, and OMOP models are evaluated comparatively. The selection is based on their documented importance for interoperable systems in Europe (Kapitan et al., 2025, p. 28; Hripcsak et al., 2015, p. 668).

The focus is on analysing the extent to which standardized procedures such as HL7 FHIR, openEHR, and OMOP can be implemented in existing national infrastructures and strengthened by overarching administrative regulatory frameworks, legally defined regulatory systems, and social acceptability. The methodological approach is structured in four successive steps: These four steps are: (1) document-based context analysis, (2) criteria-based system comparison, (3) systematic analysis of various case studies, and (4) consolidation and derivation of potential applications.

1. Document-based context analysis

A targeted compilation and subsequent evaluation of scientific literature, action plans, official reports, and technical requirements for structural interoperability models in Estonia, Denmark, Finland, and Germany. This involves the structured review, classification, and interpretation of rule-based, conceptual, and technical documents – according to the principles of exploratory document analysis (cf. WHO 2016, p. 25).

The document-based context analysis follows methodological guidelines for analysing systematic documentation of national frameworks (TEHDAS 2023, p. 8; OECD 2023, p. 11).

The selection criteria are based on topicality over the last five years and significance for scientific systems, with consideration of functional or semantic interoperability. Only sources that have been either peer-reviewed or officially published were included (WHO2016, p. 27).

Research objective and methodology

This section aims to methodically survey and evaluate the structural interoperability models in Estonia, Denmark, Finland, and Germany. The four countries examined were selected based on their heterogeneous levels of development in the field of digital networking systems (European Commission 2023, p. 6; OECD 2023, p. 13).

To this end, a document-based context analysis is carried out, which is designed in two ways: it covers both current scientific publications and government strategy and implementation documents. This methodological approach is based on the guideline-based procedure for the systematic comparative evaluation of interoperable systems developed by the WHO (2016, p. 25) and TEHDAS (2023, p. 8).

Justification of the research approach

Document-based context analysis is ideal for transnational comparative analyses in healthcare, as it incorporates both normative reference documents (e.g. legal texts, strategic plans) and standardized technical sources – such as technical interoperability models and architectural plans – into the analysis. This analytical strategy has been recognized as effective in comparable studies on eHealth system analysis (WHO 2016, p. 25; TEHDAS 2023, p. 9).

It provides a basis for illustrating the institutional, legal, and technical structures without relying on primary data. One possible methodological limitation is the lack of primary data, but this is compensated for by the structured analysis of verified official and standardized sources (OECD 2023, p. 13).

Criteria for source selection

Topicality: Publications from the past five years (2019–2025) reflecting the current state of development.

Systemic significance: The focus is on ensuring functional and semantic interoperability, primarily in the application of standards such as HL7 FHIR, openEHR, or OMOP.

Official or peer-reviewed references: official government documents, scientific research centres, global organisations (e.g., WHO OECD), European Union projects, and scientific journals.

Comparability: documents that provide statements for at least one of the countries under review.

Country selection

The countries evaluated were deliberately chosen because they represent different levels of development in the European interoperability debate:

Estonia: pioneer in technology-based healthcare (X-Road, eHealth, blockchain)

Denmark: robust patient-centred data infrastructure (Sundhed.dk)

Finland: research-friendly governance structure (Findata/Kanta)

Germany: relevant comparison due to delayed implementation despite technical potential

2. Criteria-based system comparison

The methodological approach of this study is based on an indicator-supported comparison model that systematically compares the key aspects of interoperability. I based my selection of comparison criteria on internationally recognized guiding documents. The focus was on the WHO's National eHealth Strategy Toolkit (2016), the HIMSS Interoperability Continuum Framework (2021), and the European Commission's European Health Data Space guidelines (2023). These sources provide a clear and reliable basis for a standardized and transparent method.

The interoperability frameworks in Estonia, Denmark, Finland, and Germany are analyzed on the basis of five assessment criteria.

2.1 Progress in standard application – To assess the progress of standard application, the main focus is on the extent to which international data models such as HL7 (FHIR), openEHR, and OMOP are actually used in practice. These models in particular show how far standardization has progressed in the systems analyzed (Hripcsak et al., 2015, p. 668; HL7 2021, p. 4).

2.2 Access to research information in compliance with data protection regulations – in other words, how well do institutions secure access to secondary data without violating regulatory requirements? This is precisely the focus of the assessment (TEHDAS 2023, pp. 10–13).

2.3 Management and competence structure – Management and competence structure is about more than just leadership. What matters is how organisations design leadership, coordination, and qualification so that truly interoperable control is possible (WHO2016, p. 26; OECD 2023, pp. 11–12).

2.4 Focus on patients and clear processes: How is patient-centred data used? How transparent are the data processing processes? (IHE, 2021, p. 11).

2.5 Integrative data linking between levels of care – this is crucial. This involves the analysis of cross-sector data flows and technical coupling, for example via X-Road or ePA platforms (European Commission 2023, p. 7).

3. Systematic analysis of various case studies

The case analysis uses standardized country profiles to show how Estonia, Denmark, and Finland are implementing functional interoperability. It is based on a structured comparison along the five axes of analysis defined in Chapter 4.1 (WHO 2016; OECD 2023; HIMSS, 2021).

The focus is on national, publicly accessible platforms with interoperability functions: X-Road for Estonia, Sundhed.dk for Denmark, and Findata/Kanta for Finland. The profiles are based exclusively on primary sources from the literature. These include national strategy papers such as the Estonian eHealth Strategy (2021), legal frameworks such as the Findata Act (2019), and implementation reports, for example, from Sundhed.dk (2020). A uniform evaluation grid is applied to each profile to ensure that the results remain comparable and analytically consistent. The consistency of the system profiles is systematically validated by the consistent analysis grid, even though the quantity and granularity of the underlying materials differ between countries.

4. Consolidation and derivation of applicability potential

The case studies collected are implemented relatively in order to identify nation-specific success factors and restrictions (OECD 2023, pp. 13–15; TEHDAS 2023, pp. 16–18). The intention is to conduct a methodologically sound assessment of which factors are transferable – especially for

Germany – and which systemic framework factors must be fulfilled.

These methodological frameworks open up the possibility of clarifying technical guidelines not in isolation, but implemented within organisational, legal, and social frameworks (WHO 2016, p. 31; European Commission 2023, p. 9). In this way, they contribute to the scientific debate on how interoperability can be tangibly achieved for evidence-based health research (Kapitan et al. 2025, p. 35).

The analysis framework designed can also be used and modified as an analytical tool in subsequent comparative studies on the intraoperative performance of European health systems.

RESULTS

The results follow the logic of the predefined research questions. For each question, key statements on interoperability were extracted from the analyzed country profiles and classified analytically.

Findings on the main question:

To what extent do the HL7 FHIR, openEHR, and OMOP health information models contribute to the consolidation of functional interoperability within European health systems, and which technological and institutional framework factors reinforce or impede their practical implementation?

The study shows that all three data models analyzed (HL7-FHIR, openEHR, OMOP) contribute to system interconnectivity, but to varying degrees and with different organisational anchoring. Estonia has extensive FHIR implementation in national digital health infrastructures (e.g., X-Road) (Estonian eHealth Strategy, 2021, pp. 12–15), while Finland has implemented consolidated use of OMOP for data-driven research support (Findata, 2022, pp. 6–8). Germany is making progress in pilot projects, but there is no nationwide implementation (gematik, 2023, p. 4).

1. **Results for sub-question 1:**

To what extent can HL7 FHIR, openEHR, and OMOP be used to achieve the technical and syntactic interoperability required for functional data use in healthcare and research?

Syntactic implementation of FHIR is used operationally in all four countries, albeit to varying degrees. In Estonia, API-supported communication is established in primary care (Estonian eHealth Strategy, 2021, p. 12), while in Finland, there is structural standardisation via the Kanta system (Findata 2022, pp. 6–7), and in Denmark, there are links to fragmented approaches with Sundhed.dk (Sundhed.dk 2020, p. 9). OMOP-based databases are used methodically, especially in Finland (Hripcsak et al. 2015, pp. 668–669). The infrastructural basis for application-oriented interoperability is thus in place, but only partially implemented.

2. **Results for sub-question 2:**

Which governance and implementation strategies (e.g., X-Road, Findata, Sundhed.dk) facilitate or hinder functional interoperability between academic research units and healthcare systems?

Governance and execution of the country studies illustrate that operational interoperability is strongly determined by regulatory coordination. Estonia has overarching control by the Ministry of Social Affairs (X-Road, eHealth Framework) (OECD 2023, pp. 10–11). In Finland, Findata and THL regulate central usage rights and scientific enquiries (TEHDAS 2023, p. 16). Denmark links across sectors, but in a decentralized manner (Sundhed.dk 2020, p. 12). Germany has divided competence structures, which leads to inconsistent implementation (gematik, 2023, p. 5).

3. **Results for sub-question 3:**

To what extent do Estonia, Denmark, and Finland differ in their practical application of functional interoperability, and what conclusions can be drawn from this for Germany?

Comparative analysis of Member States and implications for Germany. Estonia demonstrates advanced system integration combined with a user-friendly system architecture (European Commission 2023, pp. 5–6). Finland is characterized by science-oriented data architecture (Findata 2022, p. 7), while Denmark shows strengths in patient-oriented care and digital service platforms (Sundhed.dk 2020, pp. 11–13). Germany can learn from Estonia's administrative simplification, Finland's consistent data protection policy, and Denmark's service-oriented digital platform. The table below structures the key findings according to the evaluation criteria from section 4.2.

Table 1. Country profile comparison of operational interoperability across four EU Member States

Country	FHIR use	OMOP use	Governance structure	Patient orientation	Data integration
Estonia	Comprehensively implemented	secondary	centralized (Ministry of Social Affairs)	mittel (administrativ fokussiert)	High (X-Road)
Denmark	Fragmented	not documented	Decentralized (sectors)	High (digital services)	Medium (Sundhed.dk)
Finland	Partial	methodologically established	Centralized (Findata, THL)	Medium (research-oriented)	High (Kanta)
Germany	Pilot projects	use in individual cases	fragmented	Low	Low (partly ePA)

The results support the hypothesis that it is not only the data structure, but also its integration into coordinated governance, legal, and IT structures that determines the effectiveness of operational interoperability.

DISCUSSION

The subsequent analysis examines the results of the four reference countries against the background of the research questions defined in Chapter 2 and classifies them within the theoretical framework from Chapter 3. The aim is to identify characteristic patterns, barriers, and generalisable conditions for success for systemic interoperability.

1. Key research question on functional interoperability

The findings indicate that HL7 FHIR, openEHR, and OMOP make significant contributions to functional connectivity, but to varying degrees. The main question regarding the scope of interoperable architectures can therefore be answered as follows: FHIR is operationally integrated in Estonia, OMOP is organisationally anchored in Finland, while Germany is predominantly implementing test projects (Estonian eHealth Strategy 2021, pp. 12–15; Findata 2022, pp. 6–8; gematik, 2023, p. 4). The impact of the models depends largely on the respective system networking – i.e., the interaction between standards, governance, and digital infrastructure (Kapitan et al. 2025, p. 28).

2. Answer to sub-question 1 on technical implementation

The initial sub-question concerns technical and structural implementation. Question 1 on technical implementation can therefore be answered as follows: FHIR is integrated in a standard-compliant manner in all countries, but the degree of implementation varies (Estonian eHealth Strategy 2021, p. 12; Sundhed.dk 2020, p. 9). OMOP shows methodical research-based use in Finland (Hripcsak et al. 2015, p. 668). Operational system networking exists, but is insufficient on its own without content and operational integration.

3. Answer to sub-question 2 on governance

Control mechanisms have a direct effect on the performance of functional interoperability. The answer to sub-question 2 on administrative implementation is therefore as follows: Centrally controlled models in Estonia and Finland optimise standards-based implementation (OECD 2023, pp. 10–11; TEHDAS 2023, p. 16), whereas Germany and Denmark suffer from decentralized structures (gematik, 2023, p. 5). This confirms the WHO's call for a consistent management structure (WHO 2016, p. 26).

4. Answer to sub-question 3 on national differences and conclusions

The third sub-question deals with country-specific implementation processes. The answer to sub-question 3 is therefore as follows: Estonia impresses with its user-oriented digital infrastructure, Finland with its data-based analysis approach, and Denmark with its cross-sector integration. Germany can adapt key insights from all three countries (European Commission 2023, pp. 5–6; Findata 2022, p. 7; Sundhed.dk 2020, pp. 11–13).

5. Methodological reflection

The comparability of the units of analysis was ensured by a standardized evaluation scheme (Chapter 4.2). Restrictions exist in the diversity of document categories and the variable degrees of access to government data (OECD 2023, p. 13). Nevertheless, the methodologically structured evaluation scheme provides an adaptable analytical framework for future evaluation studies (WHO 2016, p. 25).

CONCLUSION

The comparison shows that HL7 FHIR, openEHR, and OMOP tend to be capable of supporting functional interoperability – their effectiveness is highly dependent on control mechanisms, regulatory requirements, and technical anchoring (Hripcsak et al. 2015, p. 668; Kapitan et al. 2025, p. 28). With centrally controlled systems and standard-compliant system architecture, Estonia and Finland demonstrate a more advanced stage of implementation than Germany, where fragmented structures predominate (OECD 2023, pp. 10–13; Gematik 2023, pp. 4–5). The results underscore that interoperability is not purely a technical challenge, but rather an institutional and structural one. This likewise suggests that alignment of communication practices among organisational institutions and governance stakeholders is a necessary condition for transforming interoperable data operationally usable across heterogeneous systems.

OUTLOOK

The standardisation of interoperable data architectures forms the foundation for reliable AI systems in healthcare and scientific research. A coordinated interplay of technical specifications, legally compliant access concepts, and organisational coherence is indispensable for EU-wide data space policy (European Commission 2023, p. 9).

NOTES

1. HL7 FHIR: HL7 standard for clinical data exchange. Modular resources (patient, observation, etc.) via REST APIs in JSON/XML with terminology binding (SNOMED CT, LOINC). Profiles/IGs refine resources for use cases (e.g., IPS, MyHealth@EU). Goal: fast, web-based implementation with stable semantics. Limitations: version diversity, profile fragmentation, and terminology gaps per domain.
2. OPENEHR: Open specification for semantically stable electronic files. Two-level model: stable reference model + clinical archetypes/templates. Data is stored vendor-neutrally in the CDR, queries via AQL. Strengths: clear separation of technology and business logic, high semantic consistency over time. Limitations: higher modelling/integration effort for HL7/IHE workflows.
3. OMOP (Common Data Model): Standardised CDM from the OHDSI community for harmonising observational health data. Uniform schema + standard vocabularies (SNOMED, RxNorm, LOINC) enable reproducible analyses with ATLAS/HADES. ETL transforms source systems into the CDM. Strength: cross-location and cross-country comparability. Limitations: mapping effort, sometimes low granularity without extensions.
4. TEHDAS 2023: Recommendations on semantic interoperability, terminology harmonisation and coordination structures within the European Health Data Space.
2. TEHDAS and the OECD particularly emphasise the need for standardised semantic structures and integrable reference architectures within European data spaces.
5. See ISO/TS 22600 for definitions of functional interoperability and context-related variability of health data; Kapitan et al. 2025 evaluate specific application scenarios in European systems.
4. ISO/TS 22600-1 was developed by ISO/TC 215 (Health Informatics) and defines a standardised reference model for access and authorisation management in interdisciplinary networked information systems in healthcare. See ISO/TS 22600-1:2006.
6. IHE Framework: Integrating the Healthcare Enterprise (IHE) offers a standardised process model that ensures interoperability between decentralised healthcare systems. It describes processes, data structures, and communication protocols so that knowledge content can be transmitted error-free and evaluated in a standardised manner. (see IHE, 2025)

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ФУНКЦИОНАЛНА И КОМУНИКАТИВНА ИНТЕРОПЕРАТИВНОСТ В ЕВРОПЕЙСКИТЕ ЗДРАВНИ СИСТЕМИ: СРАВНИТЕЛЕН ОБЗОР НА HL7 FHIR, openEHR И OMOP В ЕСТОНИЯ, ДАНИЯ, ФИНЛАНДИЯ И ГЕРМАНИЯ

Резюме: *Настоящото проучване разглежда степента, в която медицинските модели за данни HL7 FHIR, openEHR и OMOP допринасят за оперативната съвместимост в европейските мрежи за клинични грижи. Чрез методичен анализ на документи се сравняват четири държави – Естония, Дания, Финландия и Германия, според определени параметри за анализ. Резултатите показват ясни разлики в степента на интеграция, институционален контрол и ИТ интеграция. Освен техническия трансфер на данни, проучването дефинира концептуално функционалната оперативна съвместимост на системите като информационен процес на комуникация и организация, вграден в управленски структури, институционална координация и регулирани информационни потоци. Докато Естония и Финландия имат йерархично организирани ИТ системи с висока степен на интеграция, Германия има децентрализирани структури. Проучването показва, че ефективността на оперативно съвместимите стандарти зависи не само от техническите им спецификации, но и от тяхната регулаторна, административна и системна интеграция. Резултатите могат по принцип да подкрепят бъдещи проекти за оперативна съвместимост – особено при адаптирането на електронните платформи за грижи*

Ключови думи: *здравни системи на ЕС; функционална интероперативност; стандартизация на данните; комуникация; сравнителен анализ*

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