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A FHIR-CENTRIC APPROACH FOR INTEROPERABLE REMOTE PATIENT MONITORING

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Abstract. Interoperability of health information systems is one of the main challenges in modern clinical practice. Healthcare institutions often use different ICT solutions that do not communicate with each other, which leads to fragmented data, duplicate data, limited access to important patient information, and potential risks in making clinical decisions. The key problem lies in the absence of a universally adopted standard for the exchange of health information data. As a potential solution to this situation, the HL7 FHIR standard appears, developed to enable fast, easy, and secure exchange of health information, resulting in efficiency and consistency in patient care. This paper presents a practical implementation of the FHIR standard through the development of a specialized platform for blood pressure monitoring. The system architecture includes a mobile application intended for patients and a desktop-based application intended for doctors, which communicate via a RESTful API in accordance with the FHIR specification. The implementation demonstrates how the FHIR standard enables seamless interoperability, efficient exchange of structured data, and improved collaboration between patients and doctors, confirming its fundamental role in overcoming structural barriers in the context of modern e-health.

1. Introduction

Modern healthcare systems face significant challenges related to the interoperability of biomedical data [1]. Different healthcare institutions use different software solutions that often operate in isolation from each other, which leads to serious problems in everyday clinical practice, as patient data remains separated in different systems and there is no possibility for quick and easy access and exchange of this information [2]. Such structural lack of integration directly affects the quality of healthcare for the patient, creating barriers that prevent doctors from obtaining a complete picture of the patient's condition and making the right decision [3]. It also causes duplicate diagnostic procedures and examinations, increased costs and reduced effectiveness.

Recent advances in artificial intelligence (AI) and novel technologies have revealed transformative potential across diverse domains, including assisted and independent living [4][5], continuous health monitoring [6][7][8], robotics [9][10], education [11][12][13], and agriculture [14]. Within healthcare, AI has begun revolutionizing clinical practice through enhanced diagnostics [15][16], accelerated drug discovery, and personalized treatment optimization. However, the effectiveness of sophisticated AI models is fundamentally contingent on access to substantial volumes of high-quality, structured, and interoperable data. This dependency positions health data interoperability as a critical enabler rather than merely an administrative objective. The transformative potential of medical AI cannot be fully realized while essential healthcare data remains fragmented across incompatible systems. The adoption of robust interoperability standards represents a strategic pathway toward addressing this challenge [17].

One of the biggest challenges in health data interoperability is the management of inconsistent data from multiple sources. Data in different databases often comes in different formats and types that may not be easily compatible. A single record may contain different information about the patient's medical history or treatment plan, which makes it difficult to correctly interpret it in different systems, and thus make it difficult for systems to communicate.

One possible solution to these challenges is the use of standards. Standards are important to enable easier exchange of health data, downloading data from multiple sources to see the complete picture of the patient and to enable comparison of related data, etc. The application of standards will enable easy communication between different systems and this will result in consistency in the patient care process.

Although many different standards are used in the healthcare world today, one of the most common is HL7 FHIR. The HL7 FHIR (Fast Healthcare Interoperability Resources) [18] standard is a standard for the exchange of electronic health data. It defines resources as basic building blocks and each of them refers to different aspects of health information, for example: patients, doctors, medications, observations, etc. FHIR enables a structured representation of health data, making it easier to share between different systems and applications. The structuring of the data allows for faster and more accurate integration with other health information systems that support FHIR. Thanks to the unified structure and the use of standardized coding systems, patient data can be transferred, interpreted and reused without the need for additional transformations or manual intervention. This facilitates the interoperability between different healthcare institutions, reduces costs and creates a good basis for advanced forms of clinical analysis, chronic disease monitoring and real-time decision support.

Thanks to its flexibility, simplicity and support for modern web technologies, FHIR is the basis for the development of many interoperable solutions in e-health. In recent years, FHIR has gained great acceptance and is increasingly used in various solutions, such as electronic health records (EHR), mobile health applications, clinical decision support systems and health information exchange systems. One area where this approach has significant application is the monitoring of chronic conditions such as hypertension (high blood pressure). Blood pressure control is a key factor in the prevention of cardiovascular diseases, and regular recording and monitoring of measured values can significantly affect the long-term health outcome of the patient. In this regard, a software solution for recording and monitoring blood pressure has been developed based on the principles of the FHIR standard to enable data exchange between the patient and the doctor.

The goal of this study is to explore the application of FHIR and to demonstrate the ability of the standard to enable fast, easy and secure exchange of structured data between different healthcare systems. This application highlights the importance of FHIR as a basis for the modernization of the healthcare sector and the integration of healthcare data.

2. **Related work**

The Fast Healthcare Interoperability Resources (FHIR) standard, developed by Health Level Seven International (HL7), has emerged as a transformative framework for healthcare data exchange in the modern digital health ecosystem. In recent years, FHIR has gained substantial momentum as a solution to longstanding interoperability challenges, particularly in facilitating seamless integration between mobile health applications and electronic health record (EHR) systems. The standard addresses critical gaps in healthcare data exchange by providing a resource-based approach that leverages modern web technologies including RESTful APIs, JSON, and OAuth 2.0 authentication mechanisms. Its RESTful architecture, distinct from earlier healthcare interoperability standards, offers a lightweight and agile approach that is particularly well-suited for resource-constrained mobile environments, thereby enabling faster transmission and processing of data structures [19]. This design choice inherently addresses common mobile challenges such as optimizing battery life, by minimizing the overhead associated with data transactions [20]. Furthermore, FHIR's embrace of web technologies and common data formats simplifies integration with modern mobile development frameworks, reducing the complexity and development time for mHealth applications [21].

Recent literature analysis demonstrates accelerating adoption of FHIR across healthcare systems globally, with implementations spanning various scales from institutional deployments to national health information exchanges [22]. The standard's flexibility and modularity have enabled diverse implementation scenarios that address specific clinical workflows and organizational requirements. Research examining FHIR adoption patterns indicates that its resource-oriented architecture and support for incremental implementation facilitate gradual migration from legacy systems, reducing the technical and organizational barriers that have historically impeded interoperability initiatives [23]. The growing ecosystem of FHIR-based tools, libraries, and implementation guides has further accelerated adoption by reducing development overhead and providing proven patterns for common use cases.

The intersection of FHIR with mobile health applications represents one of the most active and consequential areas of current research and development. Mobile applications have become increasingly central to healthcare delivery models, enabling remote patient monitoring, chronic disease management, medication adherence support and enhanced patient engagement. However, the clinical value of these applications depends critically on their ability to exchange data bidirectionally with institutional EHR systems—accessing clinical histories to inform application logic while writing patient-generated health data back to medical records for clinical review. FHIR's standardized API approach directly addresses this integration challenge, providing well-defined mechanisms for secure data exchange that mobile application developers can implement consistently across different healthcare organizations and EHR vendors. The SMART (Substitutable Medical Applications and Reusable Technologies) on FHIR framework has emerged as a particularly influential specification, establishing standardized patterns for launching applications within EHR contexts, maintaining user authentication and authorization, and managing clinical context throughout application sessions.

Implementation experiences documented in recent literature reveal both the capabilities and challenges associated with deploying FHIR-based mobile health solutions in real-world clinical settings. Studies report successful implementations supporting diverse clinical workflows, including chronic disease management where continuous monitoring of patient-generated data enables proactive intervention, medication management applications that reconcile prescriptions across multiple providers and telehealth platforms that integrate virtual consultations with comprehensive medical record access. These implementations demonstrate FHIR's technical capacity to support sophisticated clinical applications while highlighting practical considerations including performance optimization for mobile networks, user experience design that balances clinical comprehensiveness with usability, and workflow integration that aligns with existing clinical practices rather than disrupting them. Many papers highlight the role of FHIR as a key standard for enabling interoperability, with different approaches to implementation - from vital signs monitoring to national health infrastructures.

Recent research presents the design and implementation of a mobile-based Personal Health Record (PHR) application integrated within a Remote Health Care Program (RHCP), utilizing the HL7 FHIR version 1.0.2 [24]. The system architecture leverages three primary FHIR resources: Patient, Observation, and CarePlan. The implementation adopts a distributed approach wherein patients input vital signs through the mobile interface, while healthcare providers define and manage care plans via a complementary web-based portal. The authors posit that this FHIR-enabled solution offers multiple benefits, including enhanced care delivery efficiency, reduced operational costs for national healthcare systems, and improved patient quality of life outcomes.

A subsequent study examined the implementation of FHIR to achieve bidirectional interoperability between a patient health record system and clinical information systems [25]. The research describes an Android-based PHR application interfaced with OpenEMR, an open-source electronic medical record system. The authors emphasize FHIR's critical role in enabling seamless data exchange between heterogeneous healthcare systems, demonstrating practical interoperability in a mobile health context.

Research conducted in the framework of a master thesis developed an interoperable platform for health data exchange, aggregation, and analysis, utilizing FHIR as the foundational interoperability standard [26]. The platform architecture correlates clinical measurements, specifically blood pressure readings, with environmental data such as pollen concentrations. The implementation comprises three primary components: a mobile application for data capture, a web-based analytical interface, and FHIR-compliant server infrastructure implemented using HAPI FHIR and FHIRBASE technologies. The authors assert that the system achieves a high degree of interoperability across all architectural components through consistent implementation of RESTful API services conforming to FHIR specifications. This standards-based approach theoretically enables bidirectional communication with any external system implementing FHIR-compliant interfaces, supporting both transmission and reception of various FHIR resource types.

At the national scale, Indonesia has deployed "Satu Sehat," a comprehensive FHIR-based health information exchange infrastructure [27]. The platform architecture integrates four core components: a central FHIR server for resource management, a terminology server for standardized clinical vocabularies, a main coordination server, and a developer center to support third-party integration. This infrastructure enables standardized data exchange across disparate healthcare information systems throughout the Indonesian healthcare ecosystem.

Similarly, Norway has implemented the FullFlow architecture, which employs FHIR-compatible protocols to facilitate secure health information sharing between patients and healthcare professionals [28]. The system integrates with Helsenorge, Norway's national digital health portal, providing patient-facing functionality. The architecture incorporates OpenID Connect (OIDC) for authentication and authorization, coupled with centralized health record management, ensuring both security and accessibility in the health information exchange process.

3. Design and implementation of the FHIR-based system

The developed system is an integrated solution consisting of two connected applications: a mobile application for the patient and a desktop application for the doctor. Both applications communicate through a locally installed Firely (Spark) FHIR server, which allows for structured, stored and exchanged health data. Figure 1 shows the workflow of how data gets from the patient to the doctor.

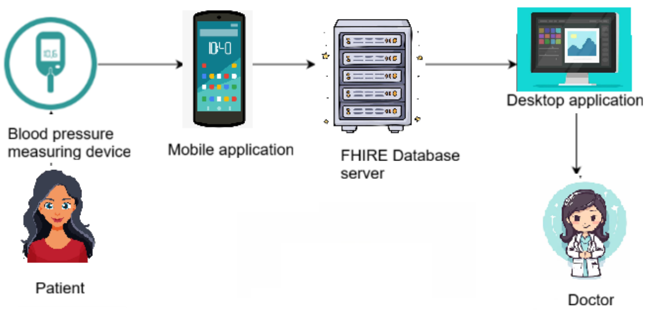

Figure 1. *Patient-to-doctor data workflow*

3.1. Mobile Application for the patient

The mobile application serves as a digital diary for blood pressure values. The patient can enter: systolic pressure, diastolic pressure, pulse and date/time of measurement. Figure 2 shows the interface for creating a blood pressure record.

Additionally, the application allows review of measurement history, graphical display of measurements, export of measurement records and sending via email.

Observation records are grouped into a package (FHIR Bundle) and exported to a text file in json format. This exported file can be saved locally on the mobile device or shared via email, offering the possibility of interoperability.

Each entered measurement is automatically converted into a FHIR Observation resource and stored on the FHIR server. Each FHIR Observation is associated with a specific patient, through its id.

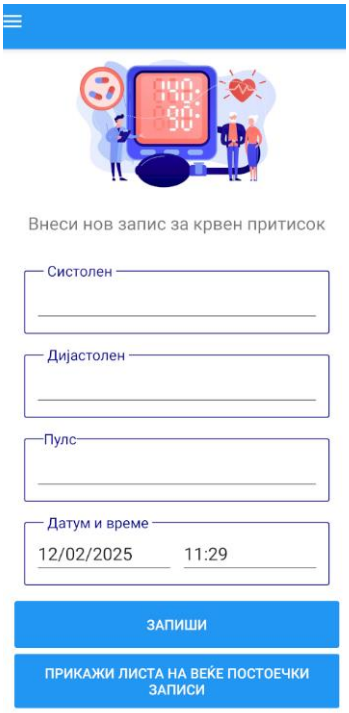

Figure 2. *Interface for creating a blood pressure record (FHIR Observation)*

3.2. Desktop application for the doctor

The desktop application is developed using the C# programming language and .NET framework. It allows the doctors to have centralized control and insight into all records entered by the patient. Functionalities include:

- View data structured by patient
- Add, modify or delete patient and observation records
- Generate a report for created blood pressure records (word document),
- Import Observations via a text file in json format, the content of which is a package (FHIR Bundle) of FHIR Observations for the specific patient.

- Export Observation records to a text file in json format and the ability to send it via email, offering the possibility of interoperability.

All changes made by the physician are reflected as valid FHIR Observation updates on the server. Figure 3 shows the initial interface of the monitoring application.

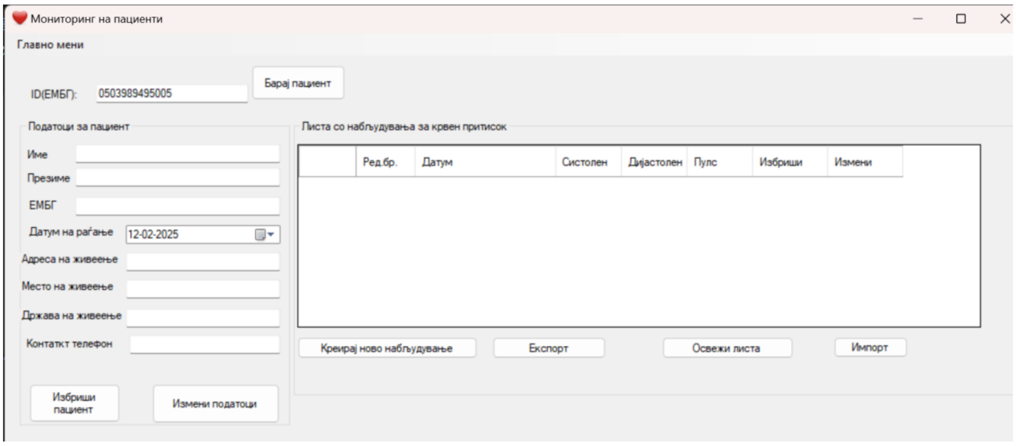

Figure 3. Initial interface of the desktop application

3.3. FHIR Resources and Attribute Mappings

• A patient is mapped to the FHIR Patient resource – it represents a patient and their demographic data. Table 1 shows the mappings to the attributes of a Patient
• An observation is mapped to the FHIR Observation resource – it contains each blood pressure measurement. Table 2 shows the mappings to the attributes of the Observation.

Table 1. *FHIR patient mapping*

FHIR Patient resource	
Field Name	FHIRattribute
First Name	HumanName.given
Last Name	HumanName. Family
EMBG	Identifier.value
Date of Birth	BirthDate
Residential Address	Address.text
Place of Residence	Address.City
Country of Residence	Adress.Country
Contact Phone	Telecom

Table 2. *FHIR Observation mapping*

FHIR Observation resource	
Field Name	FHIRattribute
Systolic	Component
Diastolic	Component
Pulse	Component
Date	Effective
Patient	Subject.Reference

3.4. FHIR Server

The system includes a locally installed FHIR spark server for data storage (https://github.com/FirelyTeam/spark), as well as the ngrok tool to make the local server publicly available. To connect to the FHIR server and work with data, the Hl7.Fhir.R4 library installed as a NuGet package in Visual Studio is used.

4. Results and discussion

The system was tested in the polyclinic “Eli-Medica Strumica”, involving 10 real patients and 2 doctors who actively used both applications for two days. A total of 83 blood pressure records (i.e. FHIR Observations) were created. The testing showed that the data exchange between the mobile and desktop applications functions stably and without any loss of information. Each measurement entered by the patient was successfully synchronized with the FHIR server and immediately available to the doctor.

The validation of the FHIR resources was carried out by checking the structural compliance of the Observation, Patient and Practitioner resources with the official FHIR specifications. No problems with data duplication or inconsistency were observed during the testing.

From the perspective of patient-doctor communication, the system enabled faster and more direct access to relevant health information. Instead of the patient carrying manual notes or unstructured data, blood pressure values were available in a standard and unified format. This facilitates healthcare and clinical decision-making.

An important aspect of the implementation is the structuring of the data during the export process. Since all blood pressure data are stored in the form of FHIR Observation resources with predefined codes and reference systems (e.g. LOINC for measurement value identification), easy transformation of the data into different formats is enabled without losing semantic information. This increases the portability and reusability of the data, enabling integration with other systems such as electronic health records, analytical platforms or national e-health registries. In addition, the use of a locally deployed FHIR server has shown that the solution can also be used in healthcare institutions without the need for external cloud services, which increases control over data privacy and security.

5. Conclusion

The developed FHIR-based blood pressure monitoring application shows that the application of interoperability standards can significantly improve the exchange and management of health data. The use of the FHIR standard allowed data to be uniformly structured, consistent and securely exchanged between the mobile application and the desktop application without additional adaptations or transformations. Testing in a real clinical environment showed that the system functions stably, without duplication or loss of information, which confirms the relevance and practical value of the applied solution.

This approach provided doctors with fast, easy and organized access to relevant data, which is crucial for timely monitoring of the patient's condition and making informed clinical decisions. On the other hand, patients gain a more active and conscious role in monitoring their own health, which can contribute to better long-term health outcomes. In this way, the solution directly affects the quality of health care, supporting a model of patient-centered medicine where the patient is an active participant in the treatment process.

Looking ahead, it is expected that FHIR-based systems will continue to play a significant role in the development of e-health services. Their ability to easily integrate with electronic health records, telemedicine solutions, and remote monitoring devices creates the foundation for a more integrated, transparent, and efficient patient-centered healthcare system.

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