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Application Notes

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A blockchain-based healthcare data marketplace: prototype and demonstration

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Abstract

Objectives: This study aimed to develop healthcare data marketplace using blockchain-based B2C model that ensures the transaction of healthcare data among individuals, companies, and marketplaces.

Materials and methods: We designed an architecture for the healthcare data marketplace using blockchain. A healthcare data marketplace was developed using Panacea, MySQL 8.0, JavaScript library, and Node.js. We evaluated the performance of the data marketplace system in 3 scenarios.

Results: We developed mobile and web applications for healthcare data marketplace. The transaction data queries were executed fully within about 1-2 s, and approximately 9.5 healthcare data queries were processed per minute in each demonstration scenario.

Discussion: Blockchain-based healthcare data marketplaces have shown compliance performance in the process of data collection and will provide a meaningful role in analyzing healthcare data.

Conclusion: The healthcare data marketplace developed in this project can iron out time and place limitations and create a framework for gathering and analyzing fragmented healthcare data.

Lay Summary

We developed and evaluated a blockchain-based data marketplace for the transaction of healthcare data. Thus, the architecture of the healthcare data marketplace has been designed. The data marketplace has developed a mobile application for personal data collection consent and a web application that allows individuals and companies to check the data collection process. We demonstrated 3 scenarios for data marketplace performance evaluation. It displayed compliance performance in the data collection process of the data marketplace. The data marketplace developed in this study will provide an opportunity to collect fragmented medical data and is expected to develop a framework for data collection and analysis.

Key words: healthcare; blockchain; data marketplace; transaction; prototype.

Introduction

The generation and accumulation of healthcare data have developed as a new field in the healthcare industry. The development of Internet of Things–based medical devices and applications has further accelerated this expansion.[1–3] Medical facilities and related companies are interested in healthcare data because of its high value for the improvement of healthcare services, personalization of treatment, and prevention of disease made possible through data analysis.[4–8] However, when medical facilities and companies use healthcare data, individual consent must be obtained because individuals have ownership of their healthcare data.[9,10] Also, it is difficult to collect healthcare data because the data are distributed and stored in different forms by different medical facilities. Further, it is difficult to compensate for data use due to the difficulty of evaluating individual data value. Transactions involving healthcare data should be achieved with guarantees of security and integrity between individuals, companies, and data marketplace. Thus, there is a need to develop a system that can facilitate the transaction of healthcare data.

As the utilization of data marketplaces increases in other industries, companies are expected to have more opportunities to explore new revenue from the collection and analysis of external data.[11–14] Recently, data marketplaces have evolved from client-server–based formats to P2P-based data

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marketplaces through the utilization of blockchain technology. Client-server–based data marketplaces can be modified and deleted by server administrators. Whereas, blockchain-based data marketplaces can play the role of an honest broker, with guaranteed data integrity and security.

Recently, studies related to blockchain have been conducted in healthcare field, such as patient participation, patient empowerment, sharing and use of healthcare data, and management of clinical trials.[15,16] Studies have included patient participation and empowerment in blockchain to help them make decisions about their care by integrating hospital information systems, such as electrical medical records and electrical health records, and the sharing of patient care information between patients and healthcare providers through mobile health and telemedicine platforms.[17–19] A study has also been conducted on the sophistication of cryptographic techniques for the anonymity of patient information.[20] Anonymization of patient information is important for clinical trial management systems in medical research. Blockchain can maintain the anonymity of individual data during such research.[21,22] The "MyData" study examines the use of blockchain to allow patients to reliably receive personal healthcare data from medical facilities.[23,24] Thus, blockchain is essential for the data transaction approach, providing not only improvements in the integrity of healthcare data and accessibility to individuals and companies but also a guarantee of individual privacy and security.

Methods

Study design

We designed a blockchain-based healthcare data marketplace to transact healthcare data between individuals, companies, and hospitals. We use MySQL 8.0, JavaScript Library, Node.js, and Android to develop a data marketplace. We developed web-based and mobile applications to make them easy to access regardless of location and time. Companies can search and transact the data through the web pages of the data marketplace. Individuals can consent to the transaction of data requested by companies using a mobile application. The National Health Insurance Service (NHIS) data were used to conduct a scenario demonstration according to the data marketplace architecture procedure. We evaluated the data marketplace through 3 transaction scenarios.

Data marketplace architecture

We designed an architecture for the healthcare data marketplace with 6 essentials: data standardization, data integrity and security, compensation for the provision of data, dynamic consent system, data matching, and transaction status monitoring (Figure 1). We consist of hospitals where healthcare data are produced, personal device of individuals who own the data, companies that want to transact individual healthcare data, healthcare data marketplace, and blockchain.

The process of data transmission between hospital and personal device

Individuals can request their own healthcare data from the hospital on their personal device. The data are then retrieved from the hospital's database and standardized to FHIR (Fast Healthcare Interoperability Resources). The individual's standardized healthcare data on the hospital server is given a hash value generated by the blockchain and transmitted to the personal device.

The process of the company's data transaction request

Companies request consent for the use of an individual's healthcare data after searching for the data that they want using the web-based application, along with details of their request, such as deadline, purpose of use, and number of data to be collected. The marketplace sends details of the request to the individual's personal device.

The process of data transmission between data marketplace and company

Individuals who receive a notification from the marketplace check the details of the request from the company and decide whether to provide their data using the mobile application. After the individual provides their consent, their healthcare data are sent to the marketplace. Health data approved for transactions are collected in the database of the healthcare data marketplace, anonymized, and parsed before being sent to companies.

Data selection

Health examination open data disclosed by the Korea NHIS were used as the healthcare data for this implementation of the healthcare data marketplace. This data is open data consisting of basic information (gender, age group, city code, etc.) and examination details (height, weight, total cholesterol, hemoglobin, etc.) on 1 million examinees for each year who have health examinations of life transition periods received by those who reach the age of 40 and 66 among these general health examinations. This data is anonymized and standardized. To demonstrate the data marketplace prototype, this data is standardized as FHIR.[25,26]

Blockchain Panacea for the data marketplace

Panacea is a healthcare data protocol, a public blockchain with an independent network. Panacea aims to make an ecosystem of patient-centric health information collection, management, and utilization possible.[27] On Panacea, records are made and validated through nodes' validation; once a record is successfully put on the blockchain, it cannot be forged or falsified. The core function of Panacea is to record the hash value of health information and to prove the integrity and ownership of the data through the hash value. Panacea can be utilized freely with its cryptocurrency, MED coin. Panacea's chain includes some information such as ID, hash value, block height, gas used/wanted, fees, memo, and transaction count. Healthcare data does not go up directly, and medical information is not contained in transactions. The main reason to select Panacea is the hash value of verifiable health information. Within Panacea's chain, healthcare data are managed in the form of Merkle tree. In the case of services that utilize a specific data format/messaging protocol (e.g., FHIR), the data go through the "Merklizing" process and assigns a hash value to healthcare data.

Healthcare data marketplace demonstration

For demonstration, we utilized Health Examination open data. This dataset does not require separate Institutional Review Board approval or similar ethical procedures for research purposes and can be accessed regularly. We randomly divided the open data into 332 001, 333 962, and 334 037 cases in each of the 3 hospitals. The performance of

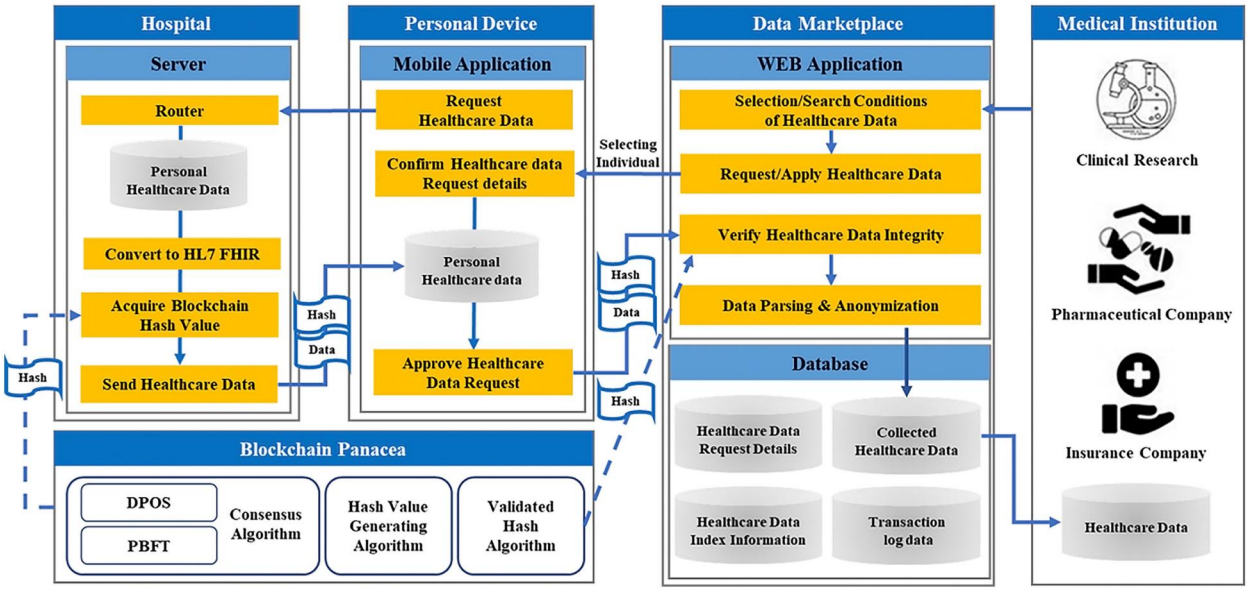

Figure 1. Healthcare data marketplace architecture. The process of transmission of data between the hospital and individual and the process of request of the data by a company.

the healthcare data marketplace was evaluated according to the time taken for the transactions. The time taken for the transactions was calculated by adding the query time to the receiving time recorded in the transaction log. The query was the time taken to apply for the healthcare data. The receiving time was the time taken to pass the data to the company from the hospital after sending notifications to the individuals. The 3 scenarios were male and obese (body mass index [BMI] ≥30 kg/m^2), male aged ≥40 years with abnormal liver function tests (aspartate aminotransferase ≥40 units/L and alanine aminotransferase ≥40 units/L) and female aged ≥60 years with high blood pressure (systolic pressure ≥130 kg/m^2 and diastolic pressure: ≥90 kg/m^2).

Results

The mobile application for personal device

We developed a mobile application that is available to individuals who participate as data owners in the healthcare data marketplace. The mobile application has functions such as pop-up notifications, inquiries for requested data information, and details of data after a transaction. Individuals can check pop-up notifications for data transaction request and consent to provide the data. The designed mobile application has been included in Figure S1.

The web page of the healthcare data marketplace

A web-based marketplace was required to provide functions for companies to search and request data and show the transaction process. The marketplace consists of searching and applying for healthcare data, monitoring the status of data transactions, and monitoring the participation status of individuals. The demonstration video of the data marketplace is in Video S1.

The web page for monitoring healthcare data transaction status

Figure 2A shows different logins according to whether the user is a company or an individual. Companies and individuals handle different tasks in the healthcare data marketplace. Figure 2B shows an initial web page for companies, where the status of data collection and transactions is monitored. It includes the type of use of the data (marketing, sales, etc.), application number, data request number and status, request date, deadline, and status of data collection. The status of data collection is presented as 1 of 3 categories: complete, incomplete, and processing. When the detail view is clicked, a page that contains details of the healthcare data application status is presented in Figure 2C. Figure 2D shows detailed log records of the data transaction.

Search and application of the healthcare data

When the application of healthcare data is conducted, companies can set the type of data collection, target number of the data transaction, deadline, and compensation in Figure 3A. In Figure 3B, additional healthcare data search diagram system is available for the company to query the application data. Selectable features are as follows: demographics (age, gender, BMI, etc.), and clinical information (high-density lipoprotein, blood pressure, etc.).

Monitoring the transaction status of individual participants

We have designed to monitor the transaction status of participants when an individual logs in to the healthcare data marketplace. In Figure 3C, the company name that transacts individual's healthcare data, type of data collection, requested date, deadline, status of the data collection, and participation status in the transacting of the data transaction are listed. The status of data transaction is presented in 3 stages: complete, incomplete, or processing. Figure 3D shows the details of the transaction when the detail column is clicked.

Demonstration of the data marketplace

In all 3 scenarios, query time was 1-2 s, receiving time was an average of 17 min, and 9.5 cases of healthcare data per minute were transmitted. The data transacted in each

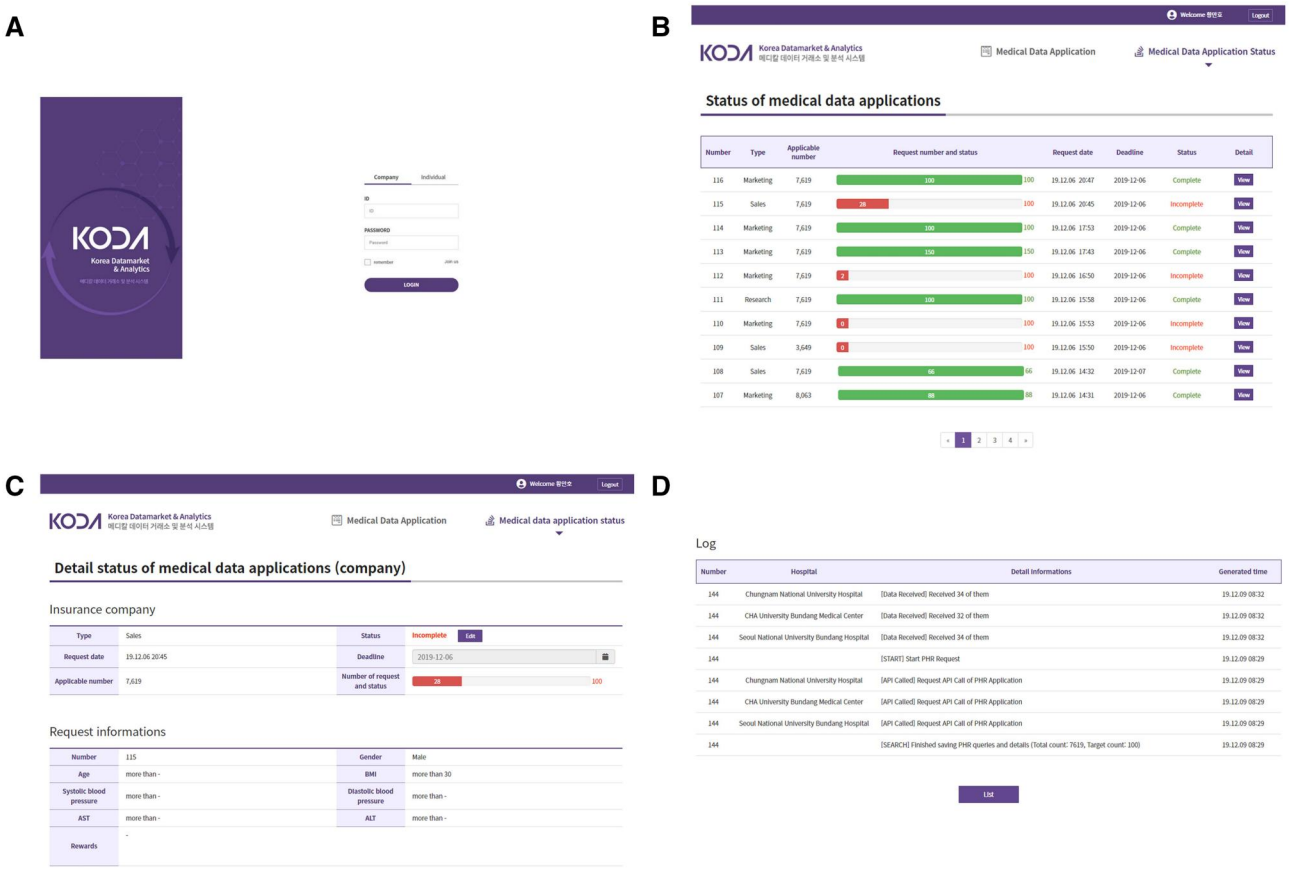

Figure 2. Login and transaction monitoring pages for companies and individual users. (A) Healthcare data marketplace login page for medical institutions and individual users, (B) healthcare data application status monitoring, (C) detailed status of healthcare data application, and (D) data transaction log history.

scenario was transmitted to each company in the form of a structured database. The result of the demonstration has been included in Figure S2.

Discussion

In this article, we have developed a web page and mobile application for running the data marketplace based on blockchain. After healthcare data marketplace was developed, we demonstrated the data marketplace in 3 scenarios. As a result of the scenario demonstration, we obtained this compliance performance for query time of 1-2 s, receiving time of an average of 17 min, and 9.5 cases of healthcare data per minute.

No previous study has proposed a system for direct healthcare data transactions between individuals and companies. Traditionally, healthcare data exchange and sharing systems have been actively studied. Hospitals have a role in mediating healthcare data exchange between individuals and external institutions, conducting multiple exchanges and transactions.[28,29] With regard to blockchain technology in the healthcare industry, research has been conducted on data management, sharing, and exchange.[15,16] Furthermore, various studies are underway to establish the medical ecosystem using blockchain technology, including research on the interoperability of electronic health records,[30] the utilization of blockchain and smart contracts for medical training certificate management,[31] surveys on the introduction of blockchain and artificial intelligence into the medical environment,[32] and the development of systems for patient management in blockchain-based medical environments.[33] However, most of these studies are related to data transaction systems between hospitals and individuals or companies.

To develop data marketplace, we utilized the blockchain Panacea. Panacea allows for the merklelization of sensitive healthcare data, enabling controlled and encrypted disclosure of only certain information.[27] It assigns hash values to specific medical data formats and messaging protocols (e.g., HL7 FHIR).[27] Consequently, the Panacea enables data access control by sensitive data owners and enhances data integrity and security through hash value assignment. In contrast, Ethereum, a widely used smart contract platform, faces challenges in encrypting data within transactions.[34–36] Additionally, Ethereum encounters scalability issues and gas costs associated with data storage and transactions, making it unsuitable for large-scale data transactions.[34–36] Therefore, Ethereum is not suitable for transactions involving sensitive individual healthcare data.

Healthcare data are stored in various formats and types.[37] It is difficult for the data marketplace to act as interoperability for the transaction of personal data. Therefore, this study was standardized with FHIR to complement the interoperability of NHIS' health examination data.[38] Therefore, we complemented the interoperability of the healthcare data

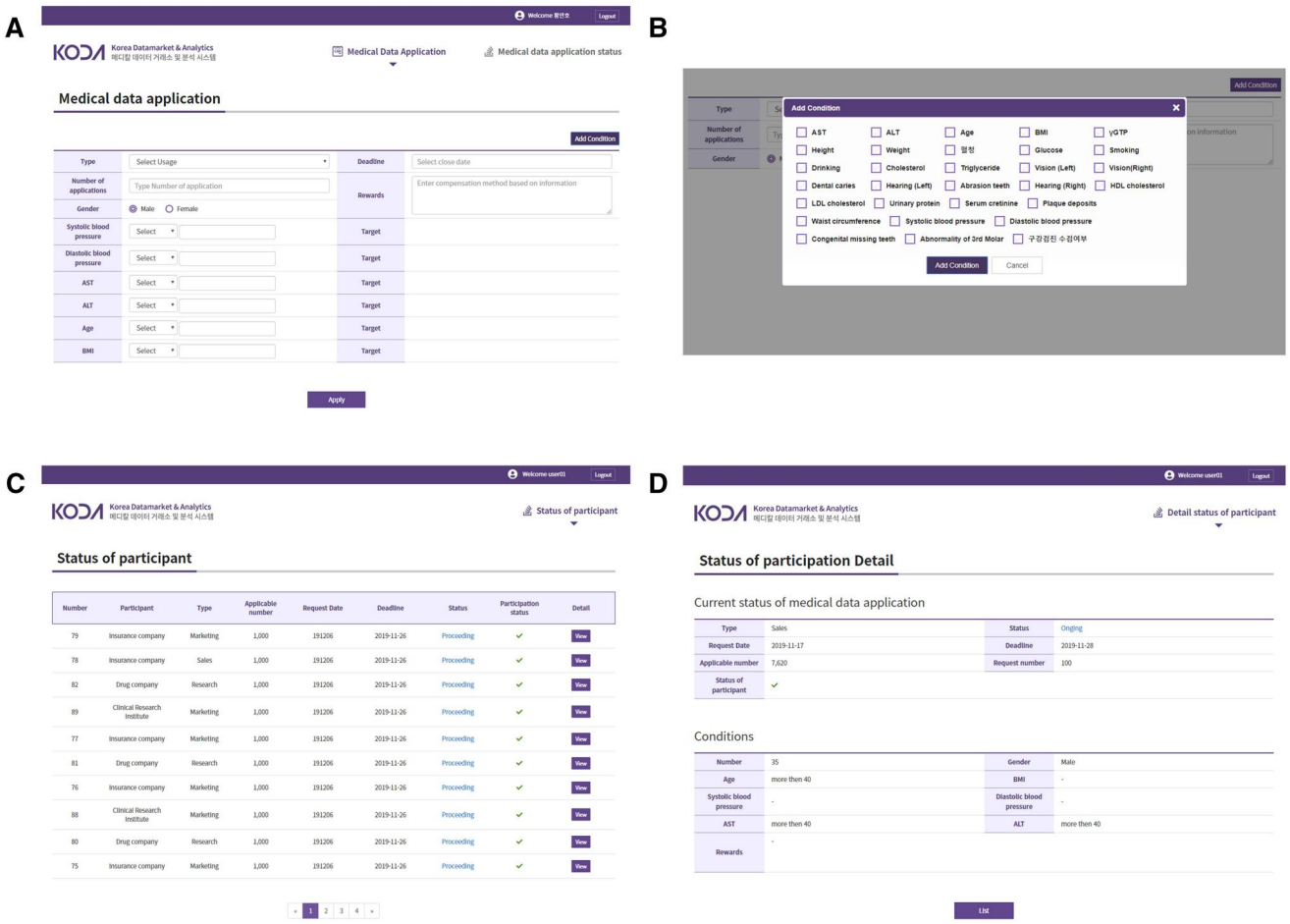

Figure 3. The pages for healthcare data search and monitoring the status of individual participants. (A) Medical data application and (B) diagram for medical data application selection. (C) Status monitoring of participants and (D) status of participation detail.

marketplace by preprocessing healthcare data in the FHIR format and recording a hash value in the Merkle tree of the blockchain.[27] Finally, for the demonstration, we used the obesity (BMI) feature and features for diabetes and high blood pressure, which are major health issues in Korea.[39]

In this study, the data marketplace is a system that acts as an honest broker, enabling direct healthcare data transactions between individuals and companies. With this feature, our healthcare data marketplace contributes to strengthening the ownership of personal healthcare data by providing a system based on blockchain. Further, the data marketplace supports a reasonable monetary compensation system and customized digital healthcare services. Companies can also save time and money that is traditionally invested in collecting personal information. Data forgery challenges are also significantly reduced with blockchain technology, making it easier to secure quality data and influencing the development of a viable application to the healthcare service model.

Our study has several limitations. First, the healthcare data marketplace model was designed to facilitate the sharing of only health examination data. In our model, healthcare data marketplace did not conduct interoperability verification for various real-world data. Second, the performance of the healthcare data marketplace should be evaluated with a larger number of individuals as participating stakeholders. Third, the healthcare data marketplace was created without considering its owner, for example, a government or private company. Fourth, there was no compensation standard for the transaction of healthcare data.

Conclusion

Healthcare data are the most fundamental resource for medical innovation, but it is owned by individuals. Therefore, the analysis was limited because healthcare data were fragmented. In particular, there are limits to money, time, and laws for collecting healthcare data. To bridge this gap, we have developed a freely available blockchain-based healthcare data marketplace. Our aim is to accelerate smooth data transactions between individuals and companies, ultimately advancing precision medicine.

Author contributions

KangHyun Kim, Sung-Min Kim, YoungMin Park, Sung Ryul Shim, Hyeong Won Yu, and Hyun Wook Han contributed to demonstration of the data marketplace and design of the demonstration process. KangHyun Kim, Sung-Min Kim, and YoungMin Park performed data preprocessing and standardization for demonstration. EunSol Lee and SungJae Jung programed the blockchain Panacea and mobile application. Jeongyong Kang, DongUk An, and Kyungil Min developed

the data marketplace and contributed to the design of the architecture, and user interface of the data marketplace.

Supplementary material

Supplementary material is available at *JAMIA Open* online.

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Conflicts of interest

None declared.

Data availability

The Health examination open data underlying this article are available in Public Data Portal at https://www.data.go.kr/data/15007122/fileData.do and can be accessed to anyone.

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