



## Research Article

## Integrating population-based biobanks: Catalyst for advances in precision health

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## ABSTRACT

Precision health extends beyond the scope of precision medicine and involves a broader range of activities, including the prediction, prevention, treatment, and management of diseases. Tailored to specific populations, precision health offers personalized treatment and preventive measures considering genetics, lifestyle behaviors, social determinants of health, and environmental factors. Precision medicine focuses on the personalized treatment of diseases, whereas precision health aims to promote health and prevent diseases using tools such as big data and advanced analytics to predict health risks and prevent diseases at the population level. Biobanks play a crucial role in achieving precision health because they provide well-characterized biological samples and related data for disease prediction, diagnosis, and treatment. Challenges in integrating different biobanks include data format consistency, privacy concerns, and legal constraints. Standardized methodologies and digitalization can mitigate these challenges. The integration of biobanks can facilitate comprehensive analyses across multiple datasets to achieve various research goals. This study proposes strategies to address these challenges, including the development of a dynamic consent mechanism for population-based biobanks using digitalization and blockchain technology. This study recommends the following: 1) integrating population-based biobanks, 2) introducing dynamic consent tools for human biobanks, and 3) using large human biobanks with dynamic consent for research on diverse diseases. These recommendations can increase the utility of biobanks in realizing precision health. A case study implemented at Taoyuan Tiansheng Hospital demonstrated the effectiveness of these recommendations for achieving precision health and enhancing the value of biobanks. Through a comprehensive examination of precision health and biobanks, this study provides valuable insights for researchers, healthcare professionals, and policymakers in the precision healthcare sector.

## 1. Introduction

General healthcare relies on the professional knowledge and accumulated experience of physicians to alleviate symptoms and reduce side effects. Precision medicine, however, considers the genetic makeup of an individual in combination with the collection of diverse data, including environmental factors and lifestyle variables, to create personalized disease prevention and treatment strategies [1–3]. Compared with precision medicine, precision health focuses more on disease prevention, early diagnosis, and treatment [1,4,5]. Human health can be classified into three categories: healthy, sub-healthy, and

diseased [6]. The sub-healthy state lies between healthy and diseased states; although an individual is not yet sick, they may have various risk factors or be at high risk for certain diseases. Early detection and intervention can prevent the development of major illnesses and improve overall health. Precision health focuses on healthy, diseased, and sub-healthy populations, thereby aiming to provide effective disease prediction, risk assessment, and recommendations for lifestyle improvements to promote improved health [1,4,5].

Moreover, according to the definition by the U.S. Centers for Disease Control and Prevention (CDC) [7], precision health encompasses a broader range of concepts, including precision medicine and public

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policy. It extends beyond traditional healthcare environments by incorporating disease prevention and health-promotion initiatives. To meet diverse needs effectively, large-scale data must be integrated across different fields through biobanks to ensure compliance with ethical, legal, and social implications (ELSI). Therefore, distinguishing between precision health and precision medicine is critical, as it primarily serves the practical purpose of differentiating levels of legal management. The dynamic consent mechanism advocated in this paper will also undergo a legal compliance evaluation, and consent forms will be revised to address the varying contexts of its application.

Biobanks, such as the UK Biobank and Taiwan Biobank (TWB), are notable examples of large-scale, well-characterized repositories that are essential for achieving precision health through the development of disease prediction, diagnosis, and treatment because of their sizes [8–10]. Biobanks can be categorized into two major types: hospital-based, which are disease-oriented biobanks used for implementing specific research and treatment, and population-based, where the emphasis is on health research and preventive care [8,10,11]. For instance, population-based biobanks, such as the Taiwan Biobank, are designed to perform broader population health research with targeted regional participation and efficient database management to support preventive health initiatives [8,10]. This distinction allows practitioners to maximize the utility of biobanks by customizing them to achieve a specific set of needs and goals. Integrating these distinct biobank types is associated with challenges, such as data format consistency, data volume, and privacy concerns.

Other challenges in using hospital- and population-based biobanks include the use of different data formats in different settings and the large volumes of raw data requiring interpretation before they can be useful for downstream applications [3,12]. Furthermore, overcoming legal constraints and obtaining consent from participants for the access or exchange of data pose substantial challenges. Standardized methodologies and digitalization can help address these challenges. Through the integration of biobanks, comprehensive analyses can be performed across various datasets for various research purposes, and integrated biobanks can promote precision health research. However, a research gap exists regarding the integration of biobanks through dynamic consent tools, digital standardization, and blockchain technologies. This is required to ensure data integrity and security as well as facilitate the interoperability of health data across different biobanks.

This study was initiated under the Pilot Evaluation Research Program for population-based biobanks undertaken by the Health Bureau of the Taoyuan City Government. In this program, the aforementioned challenges were addressed to realize precision health. This approach (dynamic consent, digitalization, and blockchain technology) has been illustrated through a case study that analyzed the use of a versatile consent platform at Tiansheng Hospital. Through preventive healthcare measures and corresponding policies, the recommendations provided by this study can promote precision health and enhance the value of biobanks, thereby providing valuable insights for researchers, healthcare professionals, and policymakers in the precision health sector.

## 2. Studies of dynamic consent and blockchain technology for biobanks

This study investigated how dynamic consent and blockchain technology can enhance the overall quality and integration of biobanks. Specifically, we developed a dynamic consent tool for use in population-based biomedical databases. Patient autonomy and control over personal information are prioritized in our approach through dynamic consent and blockchain technology to enhance data management, security, and participant engagement in biomedical research.

### 2.1. Dynamic consent

In dynamic consent, a participant-centered strategy is applied to

facilitate informed consent and overcome the static features of traditional consent procedures; in dynamic consent, technological infrastructure (often internet-based communication platforms) enables customized interactions regarding consent [13,14]. Dynamic consent focuses on establishing continuous two-way communication and a responsive consent process between researchers and participants [15]. Haas *et al.* highlighted that dynamic consent platforms provide additional advantages, such as enhanced electronic documentation of consent and the establishment of more precise and coherent frameworks for data governance [15].

To overcome the limitations of conventional informed consent methods, Dankar *et al.* introduced dynamic consent frameworks. The requirements for dynamic consent can be divided into three fundamental categories: dynamic permissions, education, and preferences. These categories use digital interfaces to enable continuous communication between participants and researchers, thereby enhancing informed consent in biomedical research. Dynamic education involves delivering educational resources to participants to engage with materials based on their needs at their own pace. Furthermore, dynamic permissions and preferences provide participants with control over their level of involvement and the research results they wish to receive. Moreover, dynamic preferences allowed the participants to select their preferred consent types [16].

In summary, the dynamic consent process fosters decision-making independence and effective communication between researchers and participants. It can adapt to the changing requirements of informed consent in an ever-evolving research landscape [14].

### 2.2. Blockchain technology

The convergence of digitalization and blockchain technologies, such as ConsentChain (a blockchain system that facilitates the sharing of clinical genomic data) [17,18] and Dwarna (a blockchain solution designed explicitly for dynamic consent in biobanking) [19], provides an opportunity for data sharing in the biobanking process. In clinical genomics, sharing data on rare genetic diseases between genetic databases and laboratories is crucial for identifying pathogenic genome variations and facilitating the diagnosis of rare genetic diseases. Historically, concerns regarding data management, governance, and security have limited data sharing. To overcome these limitations, Mamo *et al.* proposed a blockchain-based dynamic consent architecture, referred to as Dwarna, to support genomic data sharing in clinical research. Dwarna allows patients to grant or withdraw their consent for data access and enables researchers to query and access patient data stored in a secure off-chain database [19]. Huh *et al.* highlighted how blockchain technology can support the emergence of dynamic consent in clinical trials. Interactive online interfaces enable dynamic consent in which participants make detailed decisions regarding their engagement in response to changes in the research subject. The immutability and traceability of blockchain helps reduce the time requirements and improves the transparency of dynamic consent [20].

In summary, certain features of blockchain technology, namely, innate immutability, traceability, and transparency, prevent data alteration or erasure once recorded. Thus, blockchain technology is optimal for managing clinical genomic data, enabling participants to make complex engagement decisions through interactive online interfaces [21]. However, practical limitations have arisen because of data governance and security concerns that impede data sharing [17]. Therefore, this study aimed to address the existing challenges of integrating digital health data within a secure and transparent framework by introducing blockchain technology to enhance data governance and security, ultimately facilitating more efficient and trustworthy data-sharing practices among biobanks.

### 3. Recommendations for overcoming the challenges of integrating different biobanks

Precision health can be implemented using advanced technologies and transparent policies. This study provides the following recommendations to help protect the rights of participants, improve the accuracy of disease research, and reduce healthcare costs at a societal level:

#### 3.1. Recommendation 1: Integration of population-based biobanks through blockchain technology

The diversity of data formats is the first challenge in integrating the different types of biobanks. Applying uniform management models or standardized processes across biobanks is difficult when diverse data formats are involved. Despite facing challenges, the Biobanking and Biomolecular Resources Research Infrastructure (BBMRI) in Europe has exemplified successful integration efforts [22]. Although catalogs of more than 680 biobanks in Europe have been successfully unified, complete standardization of the quality control of biological data is yet to be achieved.

To overcome this challenge, a unified data format and standard should be established to ensure the interoperability and consistency of data across databases. Implementing a centralized data repository with standardized data submission and retrieval protocols can significantly enhance the efforts to integrate biobanks. Developing an open-source software platform tailored for biobanks is a flexible and scalable solution that enables biobank managers to adapt to evolving standards with minimal resource expenditure.

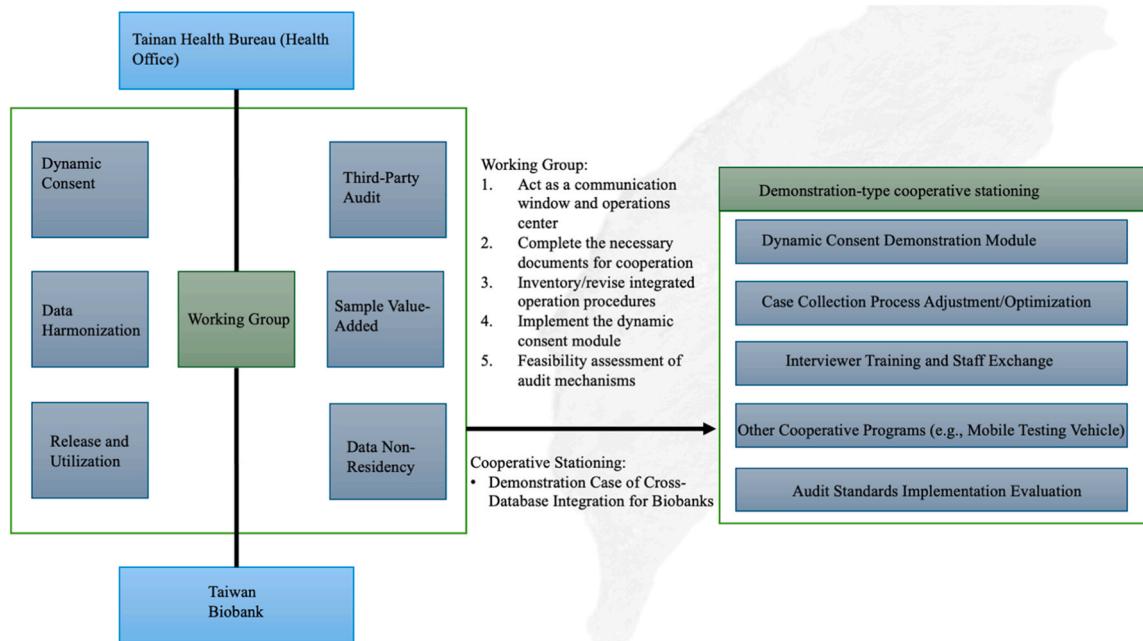
In 2010, the Human Biobank Management Act was implemented in Taiwan [23], providing basic guidelines and a unified approach to the operation of domestic biobanks. Biobank integration centers on reciprocal arrangements and resource-sharing mechanisms in addition to policy compliance and the targeting of similar biobanks. Our proposed approach is compatible with the ISO 20387 biobanking standard, which is internationally recognized for ensuring high-quality and reliable biobanking practices. This compatibility guarantees that our procedures are of the highest standard and can be used seamlessly across different countries, supporting global collaboration and data sharing in biobanking and related fields.

These measures enable the effective integration of databases. In addition, standardized practices and protocols for population-based biobanking can facilitate the integration of biobanks. Therefore, data governance standards must be formulated carefully. Fig. 1 shows a schematic for promoting the interoperability of population-based biobanks, enabling seamless data integration, and improving the practical application of data across various research and healthcare settings. The five working groups serve as communication hubs and operations centers that have important functions in preparing essential cooperation documents, reviewing and updating operation procedures, introducing dynamic consent tools, and evaluating the viability of audit mechanisms.

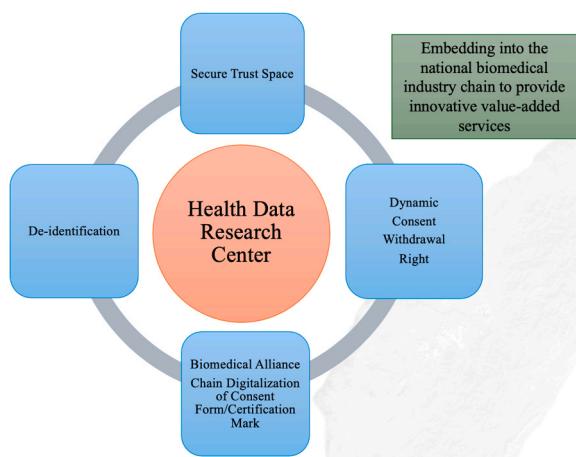
Data security and privacy protection are vital concerns in the integration of biobanks. Relevant data security measures should be implemented [24] during the integration process, such as using encryption technology and formulating clear data usage policies to ensure data security and protect the privacy of participants. Blockchain is immutable and easily verified, thereby providing data security. Therefore, blockchain technology can support the entire process of recording patient data, from creation to potential disclosure. Thus, the characteristics of the blockchain (immutability and easy verifiability) make it suitable for addressing biobank-specific challenges, particularly those regarding privacy [25].

#### 3.2. Recommendation 2: Introduction of dynamic consent tools for human biobanks

Dynamic consent tools have notable advantages and broad applicability to biobanks [17]. They provide truly “informed” consent [16]. First, dynamic consent tools increase participant autonomy and enable a comprehensive understanding of the aims, risks, and benefits of the research. Through the interactive interface and clear presentation of information, participants can easily comprehend the implications of their participation and thus provide informed consent. Second, using dynamic consent tools, even after providing informed consent, participants can withdraw their data at any time (Fig. 2). With this high level of flexibility, this research participation model centers on voluntary participant cooperation and adheres to dynamic consent principles through blockchain technology. This is the core value of dynamic



**Fig. 1.** Schematic for promoting the interoperability of population-based biobanks (created by the authors).



**Fig. 2.** Scheme of digitization of informed consent forms within the HDRC (created by the authors).

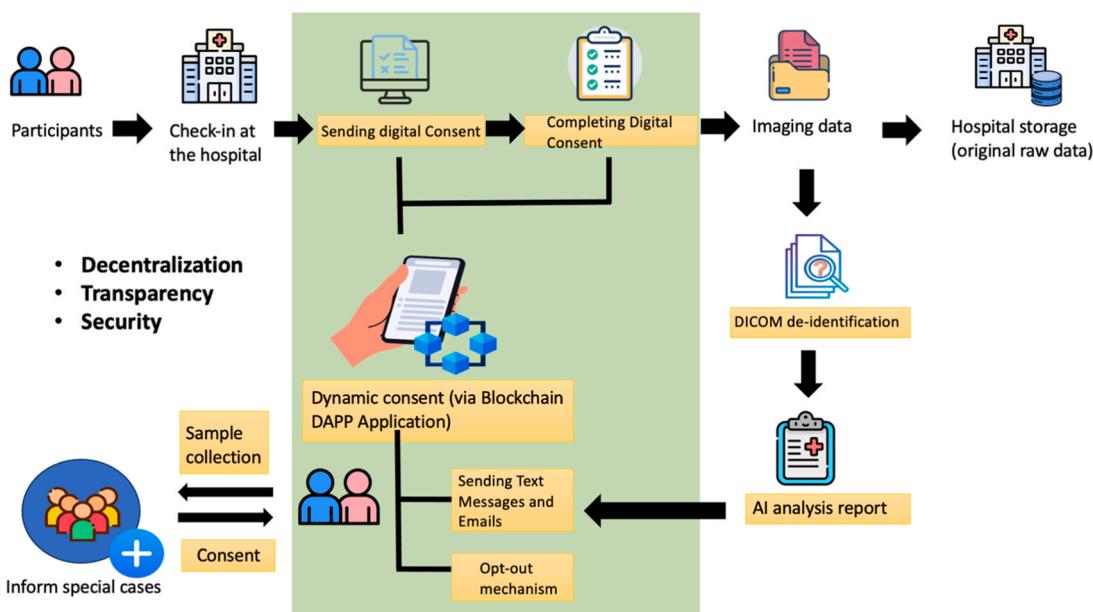
consent and highlights the respect for participants' autonomy. This is especially important when large-scale data is involved in a Health Date Research Center (HDRC) framework. This model facilitates participant involvement in information management and control over their right to participate, thereby creating a sense of safety and privacy. The features of blockchain technology enhance trust and transparency while improving the consent management process in biobanking.

Dynamic consent tools increase the level of involvement of participants in the progress of the study through the timely provision of screening results [26]. This interactive feedback mechanism enhances survey participation rates and establishes an open and transparent environment conducive to research participation. Dynamic consent tools ensure compliance with legal and ethical standards, promote research collaboration, and support interoperability among population-based biobanks. Fig. 3 shows our ELSI framework for dynamic consent, which can be categorized into four primary components: 1) autonomy; 2) dynamic consent facilitated by blockchain decentralized applications through decentralized applications (DAPP); 3) right to withdraw (opt-out), where the shift from paper to digital formats enables the blockchain to update the informed consent of participants, allowing for opt-out management through DAPP; and 4) privacy and

confidentiality ensured through the de-identification of Digital Imaging and Communications in Medicine (DICOM) data.

Data collection, preprocessing, and data mining are high-risk steps for potential data breaches. Therefore, data must be protected, and its security must be guaranteed throughout its lifecycle. In addition, data are transmitted quickly and continuously, which creates critical security risks, making them dangerous and difficult to track. Big Data are frequently shared and utilized across multiple departments in various locations, often on a daily basis. The connection of cloud-based or external sources can create unprecedented threats to privacy and data protection [27]. The General Data Protection Regulations (GDPRs) of Europe advocate the use of an intelligent contract-based dynamic consent management system supported by blockchain technology to protect personal data [28]. This system provides users with control over the collection and use of their personal information while retaining all historical transaction records in the blockchain to enhance data credibility and reliability. Within the GDPR framework, the four primary stakeholders are the data subject, controller, processor, and regulator. Dynamic informed consent was proposed to address the ethical issues in data collection for population genome sequencing programs. Dankar *et al.* argued that the definitions of the types of informed consent, such as non-dynamic, broad, and tiered consent, should be more precise and emphasized the need for straightforward informed consent processes [16].

Informed consent has become increasingly important in biomedical research. In the operation of a biobank, explaining the content of the consent form to patients is challenging [24]. The three conditions for fulfilling informed consent were providing information about the study, ensuring that participants understood it, and obtaining voluntary consent to participate. Zenker *et al.* described the importance of data protection and broad consent in biomedical research, particularly for secondary use of patient data. They indicated that the secondary use of de-identified, but not anonymous, patient data can facilitate the development of personalized therapies and learning health systems. Although most countries require patient consent for secondary use of patient data, Taiwan currently lacks a national standard. The requirements for a broad consent form are as follows: uniform textual content, broad usability, guidance documents, and mandatory protection measures. It should have a modular structure to ensure ethical compliance, institutional data protection, and information transparency. The German Medical Informatics Initiative (MII) introduced and successfully



**Fig. 3.** ELSI framework for dynamic consent (created by the authors).

established a broad consent standard in compliance with the GDPR. The process involved internal consensus-building, consultation with external stakeholders, and approval from the National Data Protection Authority. The standard prescribes textual uniformity, broad use, provision of guidance documents, and mandatory protection measures that are modular and changeable [29].

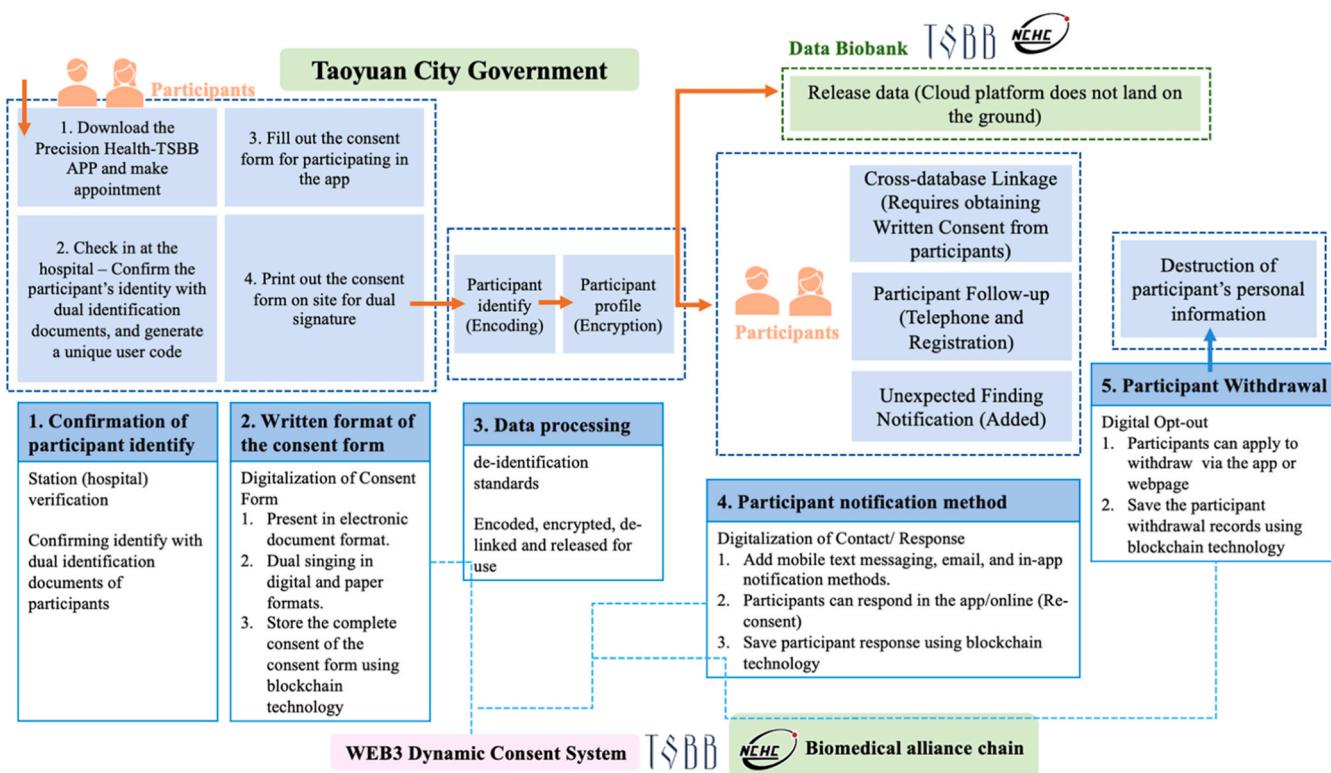
Definitions of the types of consent should be more precise to ensure the effective implementation of dynamic consent in population genome sequencing programs. Dynamic consent can be implemented by introducing blockchain-based systems and dynamic consent mechanisms, such as the Malta Biobank Dwarna [19] and the Australian Genomics CTRL systems [15]. Both systems are based on blockchain technology, which provides user control over data and ensures secure information sharing. Thus, by emphasizing dynamic consent in biomedical research, these systems can overcome the challenges related to personal data protection in the era of big data.

The dynamic consent system for the biological database of this research project was set up as follows, and the data processing approach is described. Our dynamic consent platform emphasizes the use of blockchain technology to solve personal data protection challenges. However, the implementation of a dynamic consent tool is complex and crucial, particularly for sensitive personal data and privacy. This requires careful consideration of technical decisions, system integration, user interface design, and legal compliance. Therefore, a well-designed approach should align with legal requirements, ensuring the autonomy of individuals over their data, including the right to withdraw (opt-out) online. This can give participants better control over their data, fostering trust and satisfaction [30]. Although similar blockchain technologies are used, our system is unique in three key ways: 1) it uses hashing for data uploads, 2) it is patent-protected, and 3) it does not utilize a dual-chain system. This system was digitized using the Taiwan Society for Bio-preservation and Biobanking (TSBB) Precision Health App. First, the identity of the participant is verified through a battery of steps, including verification against dual IDs, registered cards, virtual cards, and Fast Identity Online (FIDO; a set of security standards for improving

online authentication by removing the need for conventional passwords) [31], and certificates. Next, the digitized consent form is signed electronically with the option of including a paper signature. Blockchain technology is used to store the entire content of the consent form. The system then processes the data through coding, encryption, and delinking, producing de-identified data based on relevant standards. Digital methods of contacting participants, such as email, phone text, and app notifications, are recorded. Participants can participate in Q&A directly in the system through the Precision Health App. Finally, blockchain technology is used to reduce the content of the answers of participants. Participants who wish to withdraw can also do so electronically. Participants can apply to withdraw from the app or webpage, and the final record of participant withdrawal is also stored using blockchain technology.

**Fig. 4** shows a flowchart of the dynamic consent system used in the biobank maintained by the Taoyuan City Department of Public Health. This system incorporates several enhancements to ensure the robust management of participant consent, including verification of participant identity, utilization of written consent forms, data processing through streamlined procedures, timely participant notification, and easy participant withdrawal. These optimizations result in data transparency, efficiency, and participant-centric management within the consent framework of the biobank. As mentioned above, this study provides recommendations for the further improvement of this application. In the current implementation, case intake staff is required to enroll the participants [32]. The enrolment process can be automated in the future to reduce the workload of the case-intake staff, or the case-intake workforce can be increased to manage tasks during peak hours. In addition, a queuing system can be implemented to facilitate the orderly enrolment of the participants.

Self-assessment and third-party verification, as shown in **Fig. 5**, along with thorough inspection by the TSBB's framework, are essential for obtaining blockchain certification. Checkpoints include whether the system is being used as intended, whether personal data has been de-identified and whether exit and destruction processes have occurred.



**Fig. 4.** Flowchart of the dynamic consent system of Taoyuan City Department of Public Health (created by the authors).

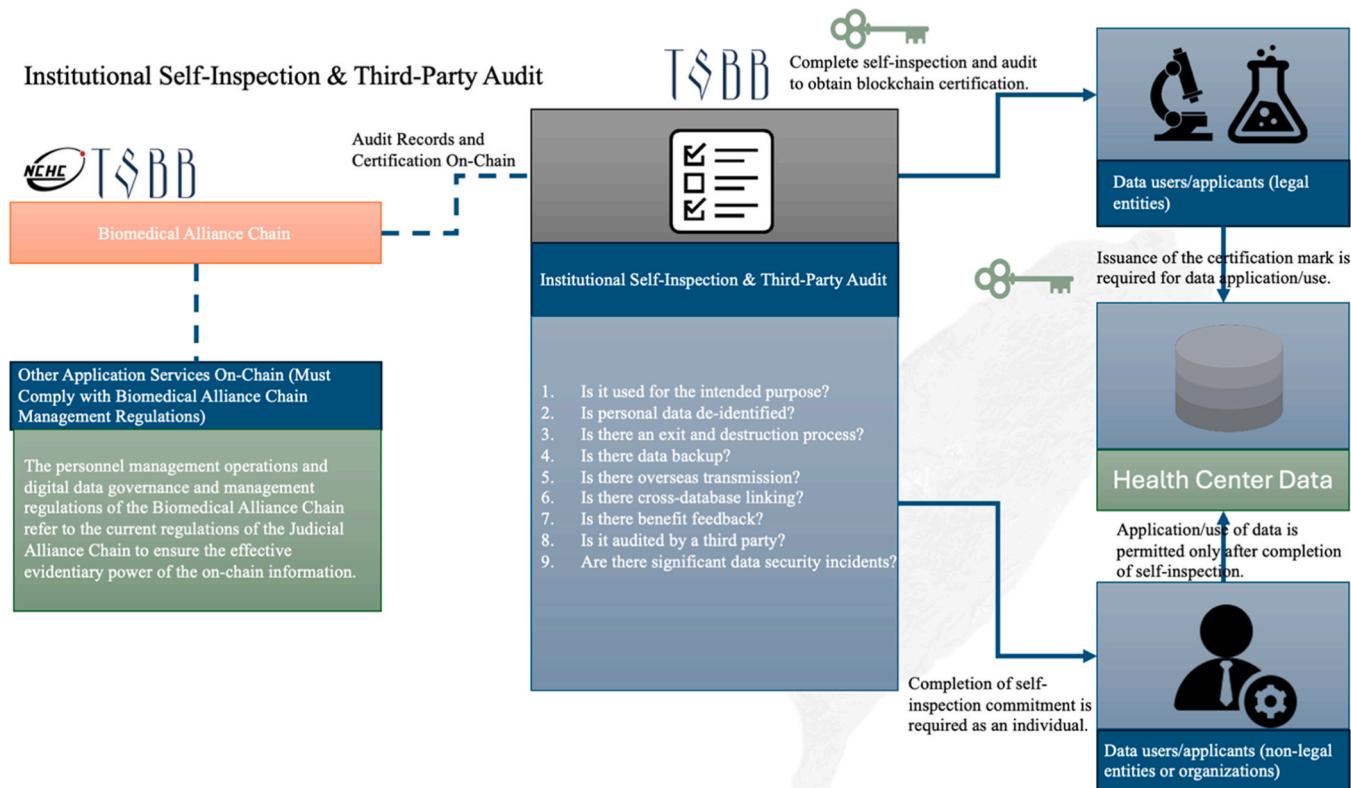


Fig. 5. Organizational self-assessment and third-party verification (created by the authors).

Moreover, data backup procedures and cross-database linking should be verified, overseas data transmission should be assessed, and effective feedback communication should be evaluated. Third-party audits should be confirmed, and significant data security incidents should be investigated. Such compliance is crucial for ensuring the privacy rights of individuals.

Furthermore, the self-assessment method of the organization should address the problem of cross-database concatenation. The consistency and integrity of data should be ensured when integrating different databases. Transparent processes and standards must be established to ensure that the data are correctly linked and interpreted [33]. Certification should indicate to the public and courts that the blockchain

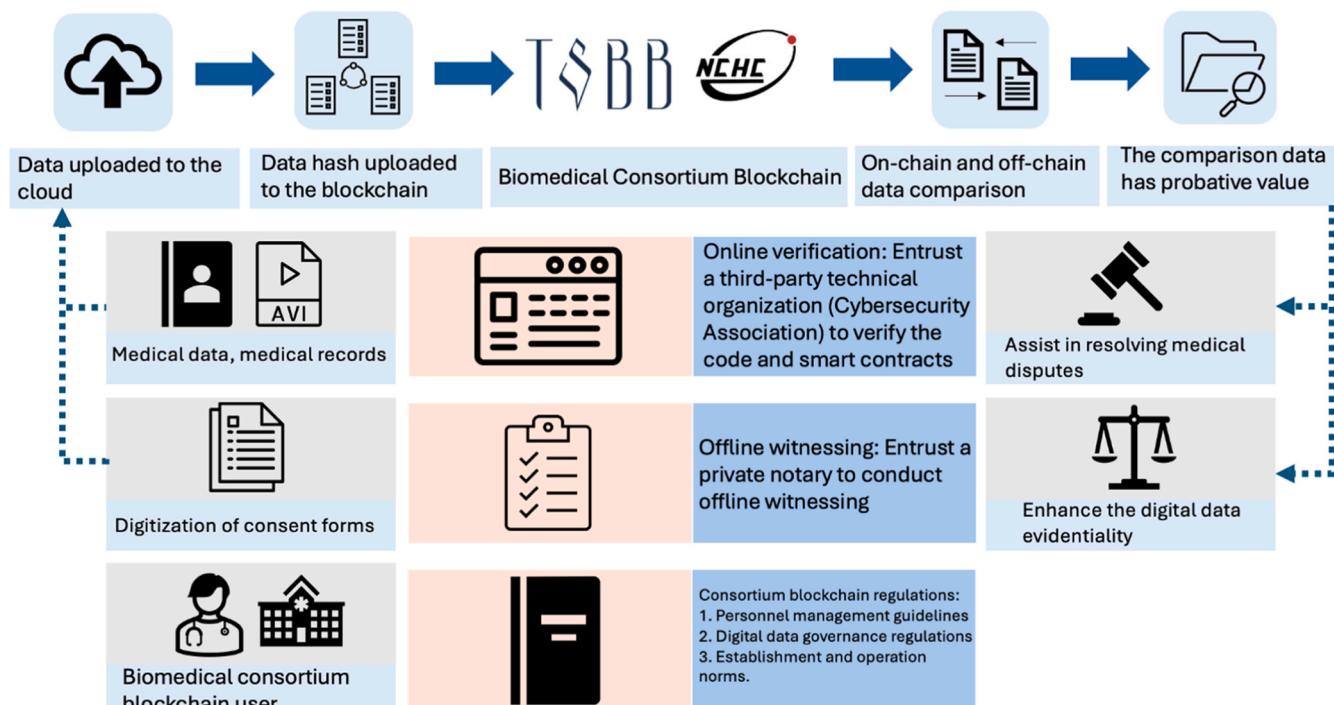


Fig. 6. Data governance and management to data stakeholders and the authorities on cloud and blockchain (created by the authors).

platform meets the fundamental security and transparency criteria. This is critical for ensuring that private companies offering similar services follow existing regulations, such as the proposed EU trade secret registry, which can be applied to biobanks.

In addition to self-assessment, organizations should proactively allow third-party checks. This ensures the objectivity and reliability of the self-assessment. Third-party verification includes assessing data use and security measures over time and providing professional recommendations for improvement. Organizations can better understand and improve their data management strengths and weaknesses through third-party checks. In addition, through third-party verification, the TSBB can show its high standard in data governance and management to data stakeholders and authorities, as shown in Fig. 6. Finally, all the data are uploaded to the cloud and “hashed” [34], a mathematical function that transforms digital data into a fixed-length output string. This ensures that, in the event of a medical dispute, the data can be compared throughout the chain, enhancing the evidential power of digital data. The advantages of third-party verification include online verification by a third-party technical organization to verify the code, smart contracts, and offline observations by a private notary. This framework ensures the strong record-keeping capabilities of the system and robust adherence to consortium blockchain regulations, including personnel management guidelines and digital data governance regulations.

Therefore, through organizational self-assessment, third-party checks, cloud-based data storage, and “hash” functions, the biodata dynamic consent tool provides a reliable foundation for precision medicine and biomedical database integration. To this end, the registry of the blockchain platform offers time-stamped proof of the existence of data, while securely and anonymously storing content with the EUIPO [35]. To protect trade secrets, the registry must maintain complete confidentiality, similar to the national IP registries of Benelux, France, and Portugal. Blockchain technology ensures the secure and transparent storage and sharing of sensitive data, thereby advancing biomedical technology and ensuring patient privacy.

### 3.3. Recommendation 3: Using large human biobanks with dynamic consent for research on diverse specific diseases

Owing to their size and diversity, large human biobanks have exceptional applications in disease-specific research. To address diverse needs, precision health requires a substantial supply of data for meaningful impact. Dynamic consent is essential in large-scale biobanks because it effectively manages complex and varied datasets. In extensive studies in which data complexity and participant diversity are high, dynamic consent offers the flexibility to cater to different needs and preferences. Therefore, by using large-scale databases with dynamic consent, researchers can efficiently collect and analyze a wide range of biological data, thereby increasing the statistical power and credibility of their research. Furthermore, it allows continuous updates on consent during long-term research projects. Although dynamic consent is beneficial for all types of data repositories, its advantages are particularly significant for large-scale biobanks.

Moreover, large-scale biobanks facilitate cross-disciplinary research collaborations and expedite research progress, providing a deeper understanding of diseases and enabling the discovery of innovative treatment approaches. In summary, large-scale biobanks provide scientists conducting disease-specific research with abundant data, allowing the development of precision health strategies.

## 4. Case study: Pilot evaluation research program for a population-based biobank

The pilot evaluation program is targeted at the integration of biobanks in Taiwan through collaboration with medical organizations [8]. By leveraging these partnerships, a robust framework for precision health initiatives can be established, and the integration of biobanks can

facilitate the seamless exchange of data and resources, the advancement of medical research, and the delivery of quality healthcare. Moreover, with technology ensuring data security and transparency, judicial oversight is simplified because members of the judiciary can redirect their focus and resources from the complex task of verifying the authenticity and integrity of electronic evidence chains to analyzing the content of the evidence [36]. Blockchain technology can thus promote the integration and improve the operational effectiveness of population-based biobanks [37]. In the long-term, this program will foster the growth of the biomedical industry of Taiwan and contribute significantly to the realization of precision health strategies.

### 4.1. Objective of the pilot evaluation research program

With advances in technology and progress made in various industries, the focus of government policies has shifted from personal medicine to cutting-edge precision health [1]. The objective is to establish a comprehensive precision healthcare system by 2030, and the program should yield long-term benefits such as fostering trust in stakeholders. In addition, resources should be integrated to realize the full potential of the program, and an effective collaboration model should be established. Throughout the project, dynamic consent tools were integrated to ensure participants' ownership and control of their data at every stage [13].

As part of the Pilot Evaluation Research Program, a detailed plan will be developed for population-based biobanking to enhance overall operational quality and efficiency across organizations. The integration of population-based biobanks is essential for implementing precision health strategies in Taiwan [8]. The program seeks to establish a comprehensive health database for the population of Taiwan, providing high-quality, multilayered information that researchers and clinicians can utilize.

### 4.2. Methodology and implementation of the program at Taoyuan Tiansheng hospital

Taoyuan Tiansheng Hospital served as the point-of-care for providing public access to the TSBB Precision Health mobile app as part of the Taoyuan Expanded Lung Cancer Screening Program Reservation Platform. Through this app, individuals can sign consent forms digitally before intake examinations. Using the Biomedical Alliance Link established by the TSBB, individuals scheduled appointments and signed consent forms electronically on the application. Digital fingerprints of the signed consent forms are also stored in the Biomedical Alliance Chain. The point-of-care test setup was conducted in accordance with established protocols. The point-of-care test environment has two key components: infrastructure provided by the TSBB and a self-built server room in the hospital. The software used for the point-of-care test was called the TWB Dynamic Consent Service version 1.0.0, which is compatible with both iOS and Android devices.

### 4.3. Application system for digital integration and standardization

Following the completion of the proof-of-concept (PoC) phase in February 2023, a total of 100 cases were collected that met the established criteria (Table 1), and 91 inspection reports were dispatched by March 7, 2024. Feedback from administrators at Tiansheng Hospital during the PoC phase led to several recommendations for enhancing the platform. First, it was suggested that the enrollment process be streamlined by integrating the enrollment platform with the application system. Upon enrolment, a unique code is generated, which instantly creates a system account with a preset password. This would minimize the interaction between the public and hospital staff, thus mitigating human error. Second, it was proposed that de-identification and APIs for DICOM image processing should be integrated. This integration automates the creation of an ID correspondence table after de-identification,

**Table 1**  
Inclusion criteria for the PoC phase.

	Expanded Lung Cancer Screening Program in Taoyuan City
Qualification of participants	Registered residents of Taoyuan City aged 40 and above who meet one or more of the following criteria: 1. Exposure to tobacco products; 2. Relevant medical history and family history; 3. Exposure to air pollution and cooking fumes; 4. Occupational exposure
Screening frequency How to apply	Once every 3 years 1. After filling in personal information on the Health Bureau's LDCT online reservation platform, you can submit an application. 2. If approved, you can schedule a screening time and select a hospital through the online system. 3. On the day of the screening, bring the QR code from the online reservation and your identification documents to the designated hospital for the screening.
Dynamic consent	A dynamic consent mechanism is provided, allowing individuals to manage the use of their personal health data. By downloading a DAPP, individuals can give consent or withdraw consent (opt-out) for the use of their health data beyond its original purpose.
AI-assisted image interpretation system	The AI imaging interpretation, certified by the Ministry of Health and Welfare, is provided free of charge to partner hospitals.

consequently enhancing the transfer efficiency and minimizing the need for manual operation. Lastly, it was recommended that the Health Bureau of the Taoyuan City Government standardize examination report formats across hospitals. These standardized formats can then be integrated into the application system to facilitate public access and enhance uniformity in report generation, thereby providing a more seamless experience to the user.

#### 4.4. Projected impact of the pilot evaluation research program on the precision healthcare industry of Taiwan

The Pilot Evaluation Research Program highlighted that dynamic consent can help address the following issues, thereby driving the precision healthcare industry in Taiwan [38]: Firstly, the underdevelopment of AI analysis hinders the optimization of big data applications across various disciplines. Secondly, the substantial expense of building data infrastructure creates major obstacles to broad implementation. Lastly, the transparency of data collection sources resulted in consistency in the accuracy of the analytical results. Significantly, Taiwan must catch up with major international powers in cultivating software development talent and advancing technological research. Consequently, the integration of software and hardware, along with dynamic consent and blockchain technology, will be the next major advancement in the digital precision healthcare sector of Taiwan. This integration is essential for enhancing current technologies and creating novel methodologies that can significantly improve precision healthcare. Dynamic consent and blockchain technologies not only ensure better data governance and patient engagement but also provide secure and transparent data management, thereby further strengthening the overall precision healthcare system.

## 5. Conclusion

The goals of Taiwan related to precision health are ambitious and include establishing a whole-person precision healthcare system by 2030. This initiative (Pilot Evaluation Research Program) aims to optimize the current healthcare system and implement a comprehensive precision health strategy. The vision of Taiwan includes the

implementation of comprehensive precision medicine that accounts for the genetic makeup, environment, and lifestyle of an individual. This goal can only be achieved through collaboration between various stakeholders, particularly in the collection and analysis of biological data for personalized medical treatment.

Dynamic consent tools ensure that participants control data usage, foster trust, increase participation, and enrich the biobank database. Thus, the realization of precise health is a significant advancement in medicine, underscoring the profound commitment to human life and health.

Moreover, the Pilot Evaluation Research Program enabled the integration of the biobank resources of Taiwan, laying the foundation for the long-term development of the biomedical industry. By enhancing the operations and quality of biobanks, the program provides reliable data for clinical trials, new drug development, and medical research, thereby driving innovations in clinical practice and medical technology. Additionally, dynamic consent tools help ensure legal compliance with the use of biological data. This increases the value of biomedical data and incentivizes the biomedical industry to address patient care and research needs more effectively. The impact of this program extends beyond clinical practice and research, contributing significantly to the biomedical industry of Taiwan and positioning the country as a leader in precision healthcare.

Overall, the dynamic consent system proposed in this study aims to improve the global precision in health research and biobanks. This approach has already secured a patent in Taiwan and has been applied in the United States. Our system has three significant technical advantages over other blockchain methods: 1) it cannot be downloaded from the platform; 2) it utilizes cloud servers; and 3) it adheres to ISO 20387 standards, facilitating cross-border usage. By leveraging advanced research and technological capabilities, precision health strategies can be implemented, positioning Taiwan as a leader in this field.

## CRediT authorship contribution statement

**Jui-Chu Lin:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Yi-Lien Liu:** Writing – review & editing, Validation, Project administration, Investigation, Formal analysis, Conceptualization. **Wesley Wei-Wen Hsiao:** Writing – review & editing, Writing – original draft, Visualization, Validation, Formal analysis, Data curation. **Chien-Te Fan:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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