



Mini review

# Precision health in Taiwan: A data-driven diagnostic platform for the future of disease prevention



Wesley Wei-Wen Hsiao <sup>a</sup>, Jui-Chu Lin <sup>a,b,\*</sup>, Chien-Te Fan <sup>c</sup>, Saint Shiou-Sheng Chen <sup>d,e,f,g,\*</sup>

<sup>a</sup> Graduate Institute of Applied Science and Technology, National Taiwan University of Science and Technology, Taipei, Taiwan, ROC

<sup>b</sup> College of Liberal Arts and Social Sciences, National Taiwan University of Science and Technology, Taipei, Taiwan, ROC

<sup>c</sup> Institute of Law for Science and Technology, National Tsing Hua University, Hsin-Chu, Taiwan, ROC

<sup>d</sup> Division of Urology, Taipei City Hospital Zhong Xiao Branch, Taipei, Taiwan, ROC

<sup>e</sup> Commission for General Education, National Taiwan University of Science and Technology, Taipei, Taiwan, ROC

<sup>f</sup> Department of Urology, School of Medicine, National Yangming Chiao Tung University, Taipei, Taiwan, ROC

<sup>g</sup> General Education Center, University of Taipei, Taipei, Taiwan, ROC

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ABSTRACT

“Precision medicine” has revolutionized how we respond to diseases by using an individual’s genomic data and lifestyle and environment-related information to create an effective personalized treatment. However, issues surrounding regulations, medical insurance payments and the use of patients’ medical data, have delayed the development of precision medicine and made it difficult to achieve “true” personalization. We therefore recommend that precision medicine be transformed into precision health: a novel and generalized platform of tools and methods that could prevent, manage, and treat disease at a population level. “Precision health,” one of six core strategic industries highlighted in Taiwan’s vision for 2030, uses various physiological data, genomic data, and external factors, to develop unique “preventative” solutions or therapeutic strategies. For Taiwan to implement precision health, it has to address three challenges: (1) the high-cost issue of precision health; (2) the harmonization issues surrounding integration and transmission of specimen and data; (3) the legal issue of combining information and communications technology (ICT) with Artificial Intelligence (AI) for medical use. In this paper, we propose an innovative framework with six recommendations for facilitating the development of precision health in Taiwan, including a novel model of precise telemedicine with AI-aided technology. We then describe how these tools can be proactively applied in early response to the COVID-19 crisis. We believe that precision health represents an important shift to more proactive and preventive healthcare that enables people to lead healthier lives.

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\* Corresponding authors at: Graduate Institute of Applied Science and Technology, National Taiwan University of Science and Technology, Taipei, Taiwan, ROC (J.-C Lin).  
Division of Urology, Taipei City Hospital Zhong Xiao Branch, Taipei, Taiwan, ROC (S.S.-S. Chen).

E-mail addresses: [reju1030@gmail.com](mailto:reju1030@gmail.com) (J.-C. Lin), [Dab67@tpech.gov.tw](mailto:Dab67@tpech.gov.tw) (S.S.-S. Chen).

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## 1. Introduction

The United States Precision Medicine initiative aims to tailor treatments to a specific “person”, taking into account individual differences in people’s genes, environments, and lifestyles [1]. Precision medicine can maximize the result of medication and reduce its adverse effects on a specific person. “Precision health,” on the other hand, encompasses precision medicine, but has a broader mandate: to predict, prevent, treat, and manage diseases. As opposed to precision medicine, which only focuses on personalized disease treatment, precision health is geared towards health promotion. It leverages the tools and methods of precision medicine, such as big data, to gather sufficient information to predict health risks and prevent diseases at the population level. In other words, precision health offers not only treatments but also preventative measures that are tailored to a specific “population”. In addition, precision medicine (geared primarily towards treatment and medicine, rather than disease prevention) can be considered as a subcategory of precision health.

Through combining big data, innovative research and development (R&D), and cross-domain cooperation, precision health offers an ambitious conceptualization of health. It relies on “dynamic” linkages between research and practice as well as medicine, population health, and precision medicine to identify disease risk factors, develop tailor made interventions, and help people lead healthier lives for providing preventive, remedial, and therapeutic measures, without incurring additional costs [2].

Based on predictions from Precedence Research, precision health-related market’s compound annual growth rate (CAGR) (including bioinformatics, big data analytics, drug discovery, gene sequencing, and companion diagnostics) during the period of 2020 to 2027 is estimated at 11.5% and its value is expected to reach US\$141.33 billion dollars by 2027 [3]. The large market value of precision health-related industry supports its inevitable growth, facilitating the development of a more generalized set of tools and methods that can be applied at the population level.

As a result of its large market value, precision health is one of six core strategic industries that have been highlighted in Taiwan’s vision for 2030 [4]. Taiwan has already launched a precision medicine initiative, and as a result, has comprehensive infrastructures and supply chains in place in the areas of health management, disease prevention, disease diagnosis, treatment and rehabilitation, as well as data science and manufacturing. Thus, the biobanking infrastructures, and large-scale storage of biological data and specimens that emerged in the wake of precision medicine, could also be leveraged in precision health [5,6]. However, there is a need for the government to accelerate the integration of these supply chains and strengthen precision health markets. In this paper, we suggest that shifting from precision medicine to precision health not only has the potential to help “populations” lead healthier lives, but also contributes to the sustainable development of precision medicine, biological big data and biomedicine, more generally. Precision health would also have far-reaching impacts because of its emphasis on population health, potentially benefitting large groups of people.

To help facilitate the implementation and improve the infrastructure of precision health in Taiwan, we have developed a series

of recommendations. These suggestions will help integrate key industries, such as medical care, personal health, and information and communications technology (ICT), as well as help achieve precision health development at the population level in Taiwan; thus, a new model of precise telemedicine will be discussed as a component of precision health. Finally, we believe that precision health can also be more proactive in responding to future epidemiological crises, taking COVID-19 as an example.

## 2. Challenges of precision health in Taiwan

Given its well-developed ICT and biobanking infrastructure, Taiwan is well placed to implement precision health; however, there are still many issues associated with implementing it at the systemic level. These barriers need to be overcome before a national shift to precision health can be achieved [7].

**The first challenge of precision health is how to reduce its cost.** Despite its many benefits, precision medicine can result in a significant financial burden for payers, patients and physicians. The high-cost problem is getting worse for precision medicine; currently, R&D of precision medicines is more expensive than traditional medicines because they require companion diagnostics and genetic testing. Not only is setting up these infrastructures costly for governments, but patients often need to withstand a larger share of medical expenses in the form of increased out-of-pocket charges. For example, Tisagenlecleucel, the first approved gene therapy to treat lymphoblastic leukemia, costs US\$475,000 dollars not just in the U.S. but also in Taiwan. It uses chimeric antigen receptor (CAR) T-cell therapy, modifying a patient’s own harvested T-cells to target the lymphoblastic leukemia antigen. Tisagenlecleucel is an alternative for patients not eligible for hematopoietic stem cell transplant (HSCT), the only curative treatment for lymphoblastic leukemia [8]. Since the drug is a personalized medicine with high efficacy, it is understandable why this treatment has such a high cost [9]. This is contrary to hypotheses that precision medicine would reduce medical expenditures. Thus, most people cannot afford precision medicine, especially in Taiwan where gene therapy costs are not covered by the national health insurance (NHI). However, most people can purchase a wearable device to track vital signs in real-time in advancing precision health. Hence, promoting precision health to serve more people might be one way of sharing these costs and gaining more public support although precision health still applies the principals of precision medicine to entire populations as opposed to individual patients.

**The second challenge relates to the harmonization of integration and transmission of specimens and biological data.** Currently, the world is pursuing precision medicine to improve the health and quality of life of human beings; unfortunately, most countries are only able to apply precision medicine to a population (e.g., patients) in need of personalized treatment [10]. Thus, we realize that developing precision health for a majority of populations (e.g., healthy people and patients) to assess health status and give interventions for preserving or restoring health is overly reliant on many different biobanks and other research databases, as lots of data need to be collected from these databases [11]. However, different biobanks have been established for different pur-

poses and have different structures, which may dissuade research units or biomedical companies from investing in the harmonisation of data for precision medicine. One of the biggest obstacles is the large amount of data that needs to be interpreted to understand the complexity of disease [12]. Overcoming different legal restrictions in different countries for accessing or exchanging data is also challenging in this regard. For instance, the General Data Protection Regulation (GDPR) in the European Union (EU) is the toughest privacy and security law throughout the EU, so its cumbersome procedural requirements might hinder international cooperation in the transmission of specimens and biological data [13].

**The third challenge concerns the legal issue of combining ICT with Artificial Intelligence (AI) for medical use.** Taiwan has a strong ICT industry due to its robust semiconductor manufacturing supply chain; however, the problem facing Taiwan's AI medical development is that relevant legal regulations still have room for improvement. For example, in 2018, Apple watch introduced electrocardiogram (ECG) to measure the electrical activity of the heart, but the function was blocked for more than one year in Taiwan due to inflexible regulations of Medical Device Act for use as a medical device. It was only on 15 December 2020 that iOS 14.3 and watchOS 7.2 for ECG were approved as Class II of Software as a Medical Device (SaMD). Therefore, some flexible regulations to fit with the trend must be legislated and combined with field applications of precision health and AI verification development to generate benefits for human's health. AI should therefore be used by physicians. However, we suggest that although AI has been shown to help reduce misdiagnosis of the diseases, many critical things still need to be determined by the physicians. Then, the physicians could double check diagnoses, and interpret patient data faster, and therefore mitigate the risks associated with inaccurate results.

### 3. Recommendations for precision health in Taiwan

**These challenges** make it difficult to implement precision health. However, we believe that Taiwan is a country that is well-equipped to overcome these challenges. Taiwan's medical care, ICT products and services are exported internationally. The main goal is to bring together a number of strategies and policies in data science, ICT technologies and AI for precision health. To help strengthen national precision health industry and align its supply chains with international initiatives, we propose the following six recommendations as justifications for Taiwan's adoption of a precision healthcare model:

#### 3.1. Recommendation 1: Integrate NHI's database with Taiwan's biobanks to reduce costs of precision health effectively and efficiently

Integrating all the available resources is the most straightforward approach to reduce cost. Precision health relies on the ability to predict disease risk and respond to early signs of illness. Therefore, accessing to large-scale biological data and human health records are required to advance precision health. However, these require massive investments in health data management, sequencing large amounts of DNA and sample storage. Thus, Taiwan's population diversity could contribute to diversity in data used for precision health. Taiwan has a diverse Chinese ethnic group, thus placing it in a unique position to preserve biological data from different ethnic groups (including aboriginal and Han populations). Integrating and using medical records in the NHI's database and the genetic profiles of donors in Taiwan's biobanks is one way of addressing some of the knowledge transition issues associated with precision medicine, and can significantly reduce expenses in this regard [14]. Taiwan's biobanks and NHI database include bil-

ions of images of computed tomography (CT) and magnetic resonance imaging (MRI) scans, as well as their associated data, which can be exchanged with a network of cooperative biobanks globally. Furthermore, with NHI's medical record, treatment with precision health might be legitimised and supported by medical insurance, and also might be reimbursed from third-party payers, such as private insurance. Nevertheless, some ethical issues might need to be taken under consideration, as there are some possibilities of breaches: (1) genetic information is shared or accessed by personnel without authority; (2) the scope of genetic information obtained is beyond the scope of the study; and (3) genetic information is used for a different purpose. Private insurance might use this information to increase profits [15]. Having access to peoples' genetic information would allow insurance companies to anticipate a person's likelihood of developing disease in the future, and perhaps charge their presently healthy (but potentially at-risk) clients higher premiums.

Taiwan has accumulated health insurance data of millions of Taiwanese citizens since 1995, which is one of the few healthcare big-data databases in the world. So far, the NHI has collected 2.3 billion image results from January 2018 to September 2020 [16], as shown in Table 1. The results of tests presented in Table 1 could contribute to improving better prevention and/or diagnosis of a particular disease (e.g., cardiovascular disease, & cancer). For example, from 2022, Taiwanese citizens can use an APP named "My Health Bank" to check if they are at high risk for cardiovascular disease. In addition, Lee *et al.* reported that biomedical researchers could use large amounts of medical data from NHI's database to detect disease-related biomarkers, and help researchers understand the severity of various diseases observed within the Taiwanese population for precision health [17]. Moreover, thirty-five variables from each laboratory test result are stored in databases that can be used for research. When combined with AI, these data can be used by academic institutions and industries to develop precision health. [17].

The NHI's database can also be used to compile newly entered patient data. Showing when individuals have been in contact with doctors and nursing staff can help us acquire knowledge of patient conditions quickly and accurately. Therefore, an integrated platform that includes the NHI's all-age health data, a cancer screening database, death files, hospital clinical databases, genetic databases,

**Table 1**  
Images Record of NHI's Database (from 2018/01 to 2020/9) [16].

Classification	Abbreviation	Cases	Number of Images
X rays	CR	17,484,898	18,658,616
	DX	15,417,666	16,373,419
	PX	231,288	242,638
Electrocardiogram	ECG	47,395	47,946
	EKG	114,162	114,599
Ultrasound	US	13,800,474	211,257,864
Endoscope	ES	2,156,087	65,239,967
Computer Tomography	CT	28,031,407	1,275,871,517
Magnetic Resonance Imaging	MR	18,179,884	610,486,891
	IO	18,765	29,136
Oral X-ray	IO	18,765	29,136
Optical Coherence Tomography	OP	111,657	398,726
	NM	55,266	113,197
Nuclear Medicine	NM	55,266	113,197
Positron Emission Tomography	PT	1,589	287,504
	SR	1,112,458	1,149,943
Structured Report	SR	1,112,458	1,149,943
Mammography	MG	134,780	263,802
Echocardiography	EC	27,279	789,478
Optical Coherence Tomography	OCT	193,758	1,055,234
	OTHER	9,771,849	191,635,061
Others	OTHER	9,771,849	191,635,061
<b>Total</b>		<b>106,890,662</b>	<b>2,394,015,538</b>

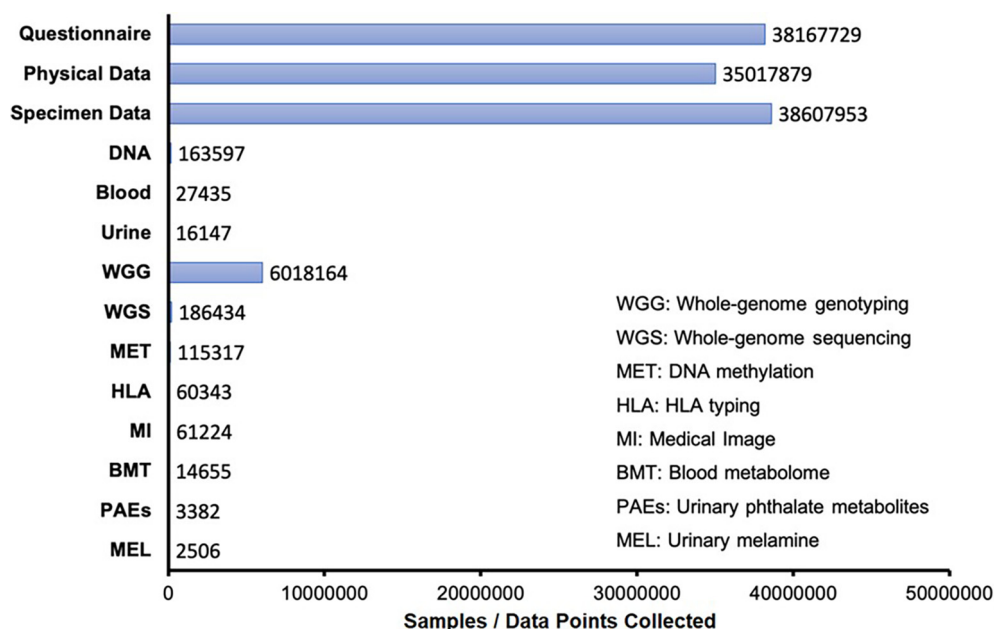


Fig. 1. Release Data of the Taiwan Biobank (TWB) [18].

and medical imaging databases would be incredibly helpful in reaching this goal.

Nowadays, Taiwan has 35 biobanks that serve as precious resources for medical research and provide a wide range of services. Amongst them, the Taiwan biobank (TWB), supported by Taiwan government, has collected specimens, health data, genetic databases, and medical imaging databases from healthy individuals (~148,000 cases) as well as those who have undergone hospital treatment (~7,300 cases), the current release data shown in Fig. 1 [18]. Just as the UK Biobank can currently use its own resources to do research, the TWB should similarly be leveraged to address important issues for medical research only. So far those data are useful for general disease prevention rather than just treatment. Thus, the TWB should cooperate with other international industries to achieve the greatest synergy.

In our previous work, Lin *et al.* also reported a framework for how to integrate biobanks vertically and horizontally [14], so that these institutions can contribute to biological science and share their data widely and globally. Currently, trying to alleviate public concerns regarding privacy infringement, subject to administrative regulations, electronic medical records (EMR) and data from NHI database can be synchronized by and under the supervision of the statistic center of the Ministry of Health and Welfare (MOHW). Among those biobanks that have been integrated under the National Biobank Consortium of Taiwan (NBCT) program, cross-bank and/or cross-data synchronization will be conducted according to the uniform standards and related clinical data management protocols promulgated by the government. The government also plans to conduct joint-tests to integrate and harmonize specifications and standards of data among different research institutes and biobanks.

Admittedly, the cost of these institutionalization efforts is huge. To help solve the cost down issue, innovative technologies have been invented and/or applied for the purposes, such as, Internet of Things (IoT), cloud computing/storage, AI and blockchain technologies. In October 2021, the MOHW officially announced a draft amendment on Regulations for Electronic Medical Records to enable legalized cloud services. It is conceivable that technological advances can reduce the costs of data synchronization, simplify and standardize data collection, and turn data into reliable infor-

mation for doctors, patients, and health individuals. This could create a new model of operations in health care.

However, implementing telemedicine and uploading personal medical records to cloud services raises legal and/or ethical concerns relating to information security, sensitive personal privacy protection and benefit-sharing issues, which might deteriorate social trust. As a result, institutionalization efforts need strategies to cope with these challenges. The government-sponsored Electronic Medical Record Exchange Center (EEC) was created as an independent collaboration platform in Taiwan to implement Fast Healthcare Interoperability Resources (FHIR) standards for future international compatible medical data integration. The platform serves as the basic foundation for ELSI compliance for local and/or international medical care and research collaborations.

In regard to the FHIR standard implementation requirement, three critical elements need be satisfied with related regulations: 1) Empowerment, 2) Access safety, and 3) Openness. “Empowerment” has been an international trend. It encompasses the autonomy of participant/patient’s broad and dynamic consent, along with legalized opt-out mechanisms, and is a foundational part of enabling cross-database and cross-border research for the common good on the global scale. The UK Biobank and “All of Us” in the U.S. currently serve as the two leading models in the world for handling personal data. “Access safety” and “Openness” are jointly subject to the above-mentioned FHIR complementation works, including, but not limited to, the inclusive coverage of the National Information Security System and the application of innovative technologies, such as blockchain, which offers a possibility to back up with these trust-building efforts. It also equips participants/patients with cost-effective personal information devices and an APP to facilitate the mobility of their engagement and utilization of their personal health data. In turn, “Access safety” and “Openness” can be better assured.

Furthermore, precision health could use the Whole Genome Sequencing (WGS) data as a valuable resource. The WGS data of the TWB is the largest publicly available genetic database of Han Chinese ancestors and Taiwanese Indigenous peoples [18]. For example, the Taiwan Precision Medicine Initiative (TPMI) used WGS data of the TWB to study a gene mutation map, and a clinical database, which includes clinical drug efficacy and side effects, as



well as clinical research data [19]. The TPMI intends to complete a cohort study of 1 million patients with general diseases within three years, which could potentially be used to promote precision health in the TPMI [20]. Precision health resulting from genetic studies is beneficial for the population whose genomic material has been analyzed. In other words, the TWB can be precisely used as a foundational genomic resource for individuals closely related to Han Chinese ancestors and Taiwanese Indigenous peoples. Nevertheless, TWB has made a huge impact on precision health as TWBv2 array data WGS data from 1492 individuals and genome-wide SNP data from 103,106 individuals of Han Chinese ancestry using custom SNP arrays, thereby making research on precision health convenient. Recent research has shown that a model for precision health management can be achieved by combining comprehensive genetic testing and aggregated data according to ancestry/ethnicity and geographic locations. This is because different populations from different genetic backgrounds have different disease susceptibilities and drug metabolisms [20]. However, precision health still requires the development of large-scale biochemical and genomic resources for a wide range of ancestry groups, aside from the Han Chinese and Taiwan indigenous peoples, in Taiwan, such as new immigrants (most are from southern Asia).

### 3.2. Recommendation 2: Align international data transfer regulations with global protocols

Regulations surrounding international data transfers are critical. However, different countries have different legal restrictions and standards regarding the use of patient information for research or commercial purposes. This presents a number of obstacles that dissuades research units or biomedical companies from investing in the development of precision health. In addition, there are organizational barriers (e.g., different operating procedures) that can prevent Taiwan's 35 biobanks from sharing information with each other. Thus, it is critical to integrate most of the Taiwan's biobanks to establish a worldwide platform of international data exchange

in relation to ethical, legal, and societal issues (ELSI). For example, the European Commission proposed the GDPR in 2012 [21]. The vague conditions and regulations of the international flow of personal data in the GDPR have been widely criticized. This is because its cumbersome procedural requirements are not conducive to international cooperation in biomedical research [13]. If companies or research units want to use biobank data as research materials, they have to contend with ethical concerns surrounding the infringement of personal privacy. There are a number of legal challenges associated with the international transfer biological data or specimens for research or commercial use, such as Article 15 (restrict for international transmission) and Article 20 (restrict for purposes other than biomedical and medical research) in the Human Biobank Management Act of Taiwan [22]. Therefore, the use of personal data (e.g., medical records) brings up a number of ethical issues. Illegal data usage could be used to target vulnerable populations (e.g., people with poorer health status), as this information could be distributed inappropriately, and result in patients losing control of their own data. For example, data collected by the biobanks cannot be used to discriminate people from insurance/employment. Thus, the biobanks often have rigorous procedures in place to prevent illegal data usage. The biobanks should ensure de-identification of data when sharing these with industry or academic collaborators. The details of the TWB's standard operating procedures (SOPs) are shown as an example in Fig. 2. The SOP offers a set of step-by-step instructions for domestic and international applications, in accordance with medical and personal data protection laws. This minimizes communication issues and failures to comply with the regulations of biobanks in different national contexts. For the international applicants, notice that Article 15 of the Biobank Act, which governs international transmission, states that any international transfer of biobank data, as well as the export of any derivatives, must be approved by the MOHW. Consequently, compared to domestic applicants, due to longer review time and higher rejection rate, the international applicant is agreed to submit a payment after the review and approval of the MOHW.

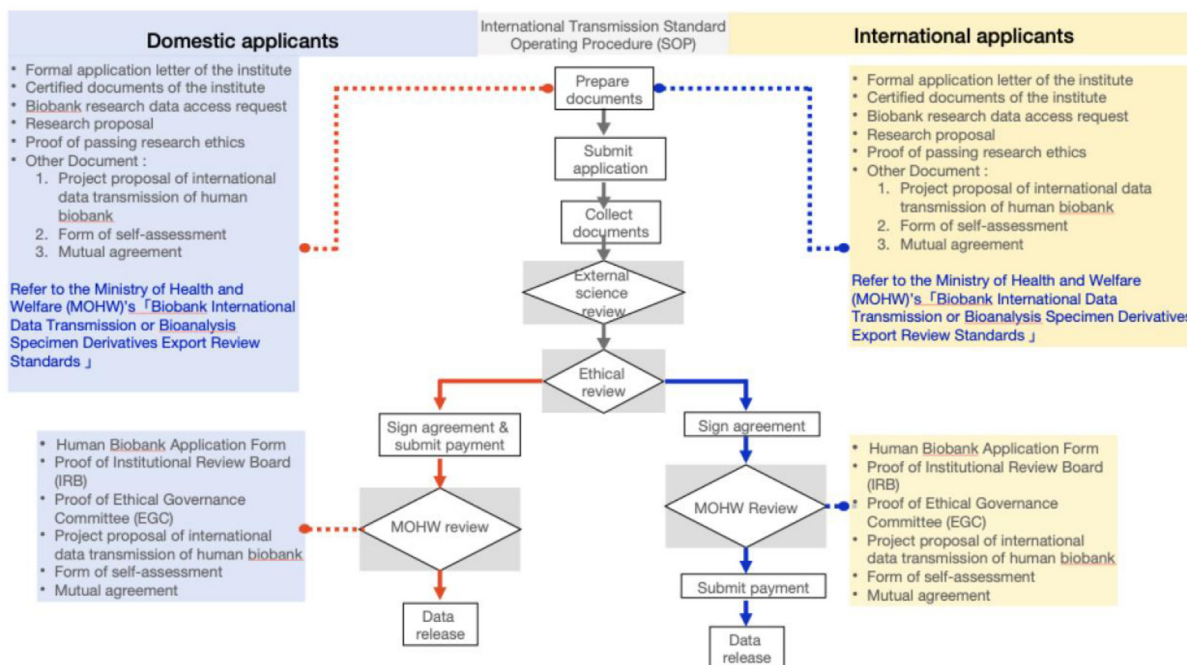


Fig. 2. International transmission standard operating procedures (SOPs) of the Taiwan Biobank (TWB) [18].

### 3.3. Recommendation 3: Establish an innovative and flexible ICT ecosystem for precision health

Taiwan's infrastructure in the precision health industry is very robust, and is comprised of mobile health care, smart medical equipment, smart hospital solutions, 5G, AI, cloud computing, and other digital technologies for providing healthcare-related support services. Of course, these digital technologies were not specifically designed for the precision health industry, but for other technological sectors too. Although Taiwan plays an important role in global supply chains in the R&D of various medical applications, Taiwan still has an immature venture investment ecosystem.

ICT, powered by 5G, AI, and cloud computing, can speed up precision health diagnoses and make these medical services available to the next generation of patients and health care workers. In other words, the use of big data technologies can accelerate the development of new drugs and models of risk assessment — outcomes that have great biomedical potential as well as industrial value. Taiwan is a well-developed ICT manufacturing hub that can be leveraged to use this device in a precision healthcare setting. For example, a diabetic patient needs to monitor blood sugar over time. The Taiwan Biophotonic Corporation. (tBPC) has developed a non-invasive, portable glucose meter capable of tracking people's glucose levels continuously without finger pricks [23]. Thus, when the patient receives the data transmitted by the device, he/she can manage the level of blood sugar with diets or medicine. These kinds of devices have been incessantly developed and introduced to the market for providing advices or measures taken for prevention of disease, indicating that the era of precision health is just around the corner.

Moreover, Taiwan's outstanding performance in integrating medical and ICT industries has created a niche market globally. For instance, Taiwan government plans to apply digital technology, big data and AI to a variety of emerging medical industries, such as precision health, in Taiwan's vision for 2030, in order to prevent or combat diseases for the benefit of citizens' health. However, so far in Taiwan, the healthcare sector is often faced with regulatory restrictions that limit the use of new technologies and hinder the advancement of product innovation, such as telemedicine and AI-aided medical technology. There is a need for more flexible policies and regulations, as innovative support between the ICT and medical industry are crucial in the advancement of precision health in Taiwan. Nguyen *et al.* proposed dynamics of national ICT ecosystems that should not be only viewed as technical systems in isolation, but also include non-technical dynamics, being socio-economic, political, and spatial [24]. Hence, we suggest that Taiwan government should construct an integrated platform for health big data and legislate forward-looking and flexible regulations to enable the ICT industry dynamics and improve the ICT ecosystem in Taiwan.

### 3.4. Recommendation 4: Introduce AI-aided medical technology for precision health

Without a doubt, biobanks are crucial for the implementation of precision health. Notably, some medically advanced countries such as the U.S., the U.K., Japan, and Taiwan have already developed biobanks to maintain biomedical big data of patients or healthy people for research purposes [24–26,14]. Moreover, progress in the area of information technology opens up a myriad of possibilities for data storage, processing, and its application to health care systems [27]. In the past, practitioners believed that the human proteome was comprised of about 2000 proteins. Now, more than ten-times that number of proteins have been discovered, and this value is expected to increase [28]. These big data serve big expectations in the precision health. Biobank structures are capable of

storing an enormous amount of data. These collections of data can then be processed to study past and present diseases, and avert and even prevent the damage done by them. Biobanking infrastructure has been involved in the R&D of precision medicine [29], but now it is a key element for precision health. With the help of AI programs and big data, biobanks possess even more significant functions [30]. For instance, a physician might need to view hundreds to thousands of X-ray images a day. Thus, some mistakes are inevitable. AI can help reduce this burden by helping health providers analyze these images more efficiently. Nevertheless, the people creating algorithms for AI are not always physicians that possess the requisite medical knowledge. While AI can help with diagnosis and basic clinical tasks, physicians are still needed to confirm results and provide treatment.

In addition, big data from biobanks can be used to better train AI algorithms to conduct disease diagnosis. Through deep machine learning, AI will help biobank users to review data, forecast an occurrence, and assess risk factors for biomedical research. As a result, AI will be able to successfully exploit big data from biobanks in precision health to prevent disease, hasten recovery, and save lives. Therefore, AI is critical for managing big data from biobanks and improving disease diagnosis in precision health.

Furthermore, an AI-aided medical robot or an AI-driven application could potentially convey medical knowledge and remote medical staff or family members quickly and accurately grasp a person's physiological conditions. For example, Inventec Appliances Corp., a Taiwan-based company, sells EASY DOCTOR in domestic and foreign markets, a multi-physiological system, which can be used to monitor blood pressure, blood glucose/total cholesterol/uric acid and ECG via the ICT technologies [31]. Thereafter, before going to a clinic, the person could upload his/her physiological information to a cloud health database and also to get immediate information about his/her health status. Through integrating health databases and AI technology, the AI-aided medical robot or app could learn about the current conditions of an individual (e.g., the severity of symptoms from the physiological signals). Later, the person could be instructed on how to see a doctor according to their assigned medical classification. Zeevi *et al.* developed an AI that integrates blood parameters, dietary habits, anthropometrics, physical activity, and gut microbiota. It accurately predicted personalized postprandial glycemic responses to daily meals. This information would allow people to have their own tailored dietary recommendations to control their glucose levels, rather than relying on universal recommendations which often only have limited utility [32]. Another useful AI invention, CrossCheck, is a multimodal data collection system designed for continuous remote monitoring and identification of digital indicators of psychotic relapse [33]. CrossCheck has also been used to track/monitor the progression of dynamic phenotype, in order to diagnose children with risk of autism. As neurodevelopmental conditions like autism are dynamic. AI and data science will enable diagnostics to be more scalable, accessible, and precise [34].

In the past, there were many successful examples of AI applications in medical image recognition. For example, AI applications can help precision medicine through analyzing EMRs in Ophthalmology to improve ocular disease diagnosis, risk assessment, and progression prediction [35]. Analyzing population-level data is, admittedly, more challenging, especially when health records are combined with information about an individual's genetics, behaviors (e.g., exercise frequency and eating habits), and environmental factors (e.g., air quality, humidity, & temperature). This massive amount of information to predict or even prevent diseases will require more advanced AI-aided technologies, as shown in Fig. 3. Therefore, there is still a lot of room for development of AI-aided technology in the transition from precision medicine to precision health in the future.

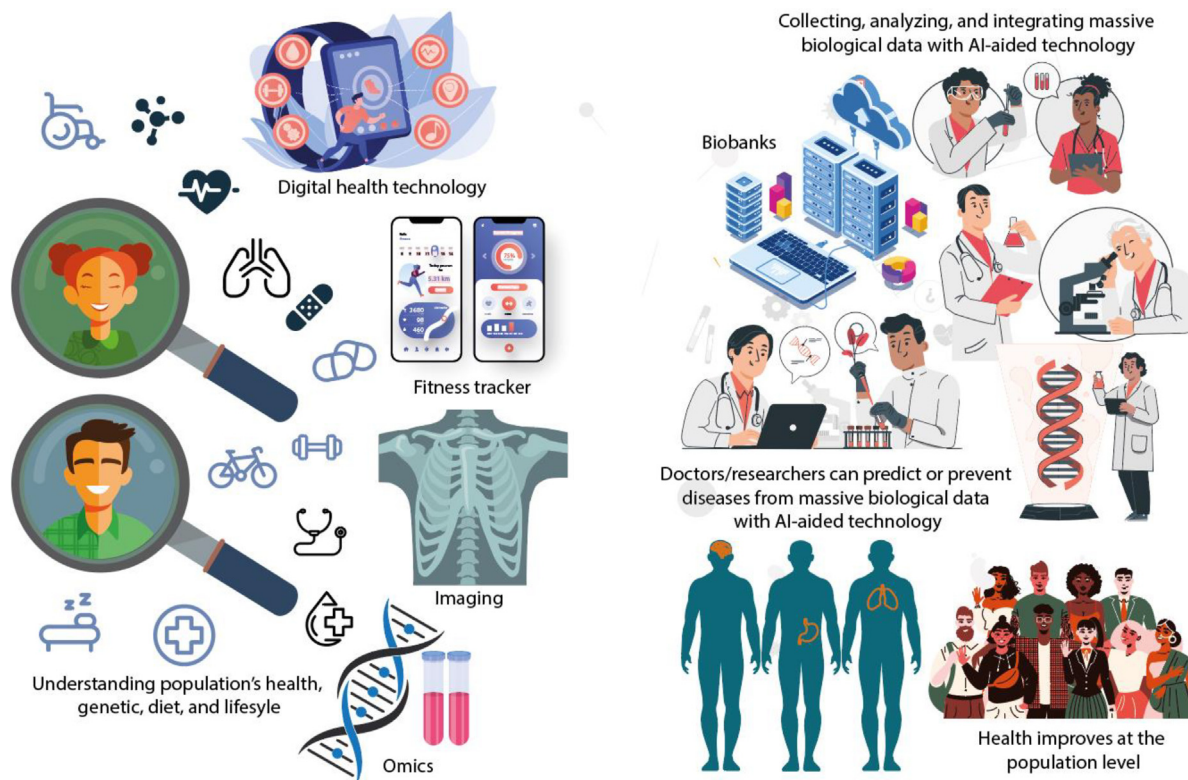


Fig. 3. Model of AI-aided Precision Health.

3.5. Recommendation 5: Launch a “precise” telemedicine with AI with flexible regulations

Telemedicine is an on-line service to diagnose and treat patients remotely via telecommunications technology to provide efficient and cost-effective healthcare. As demonstrated in Fig. 4, to reap the benefits of precision health, an innovative model of AI-aided

telemedicine called “precise telemedicine” combines advanced technologies such as big data and AI to help address population health [36], thereby considered as an extensive application of precision health. According to the Article 11 of the Physicians Act in Taiwan, telemedicine can be legally applied to mountainous areas, outlying islands, remote areas, or under special or urgent circumstances, such as the ongoing COVID-19 pandemic [37]. How-



Fig. 4. Model of AI-aided Telemedicine.



ever, so far the act does not define any treatment that may be assisted by AI. Therefore, we suggest that physicians should be still an indispensable feature of AI-aided health systems. Although AI has been shown to help reduce misdiagnosis, physicians are still an integral part of health service delivery and need to be physically present to provide medical advice, inform medical decision-making, and prescribe treatments.

Moreover, we also suggest the regulations in the Physicians Act of Taiwan should be flexible to expand precise telemedicine services to overseas markets and help neighboring nations. Hence, government support of digital development can accelerate the establishment of a workable platform for basic products, brands, and their international export. In addition, the government of Taiwan must strengthen the effectiveness of regulations, especially the emergency authorization regulations established during the current epidemic so that Taiwan can excel in international competition. Lastly, Taiwan’s strengths in semiconductor technology can be used to develop precise telemedicine-related devices that ensure data accuracy and better monitoring [38].

### 3.6. Recommendation 6: Increase proactivity in responding to COVID-19

As of 8 February 2022, approximately 397 million confirmed COVID-19 cases (including 5.7 million deaths) have been reported to the World Health Organization (WHO) [39]. Large-scale biological data, such as those found in biobanks, enable early detection of outbreaks and other community health issues. The ICT and AI can also be used for ongoing surveillance by tracking population movements and contacting potentially infected individuals. For example, during the COVID-19 pandemic in Taiwan, Google Maps (either through smart phones or wearable devices) was mobilized in contact-tracing [40]. This shows that the ICT technology is indispensable to collect useful data for precision health. Moreover, understanding the viral spread and pathogenesis of COVID-19 in different populations could help treat the virus. Thus, biobanks could be used as an archive of data from former pandemics. The big data provided from the previous pandemic, the 2002 SARS outbreak, for example, is being utilized to identify strains of the virus in the current pandemic [41].

Wang *et al.* at National Cheng-Kung University in Taiwan has developed an AI-based pneumonia detection platform named “MedChEx.” This platform uses chest X-ray images to detect COVID-19 symptoms. Notably, 95.5% of sensitivity and 99.0% of specificity (from 1,363 test images) can be researched with this noninvasive diagnostic system [42]. This kind of AI-based system

can dramatically improve the speed of COVID-19 detection since X-ray machines are more readily available and take less time to process results than RT-PCR machines. In addition, the development of noninvasive screening tests reduces the physical discomfort and infrastructural burden of nasal swab tests. Furthermore, even in remote areas, AI-based techniques can quickly detect viruses and effectively prevent the spread of disease, representing a great advantage for precision health system. In addition, physicians can take advantages of AI-guided remote care in preventing, diagnosing, treating, and controlling the symptoms of COVID-19 [43].

## 4. Conclusion

Precision health in Taiwan can leverage the country’s high-quality medical system, well-developed ICT industry chain, big data accumulated in the NHI’s database and biobanks, and R&D infrastructure in relevant areas. Thus, applying these advantages in ICT and health care services to develop a precision healthcare sector has become a high-level priority among all sectors of industry and academia.

In the era of COVID-19, Taiwan can take advantage of successful health and epidemic prevention safety models to further benefit the country. Thus, as shown in Fig. 5, we proposed a framework with three recommendations for facilitating the development of precision health at a population level: **(1) Integrate NHI’s database with Taiwan’s Biobanks to reduce costs of precision health effectively and efficiently.** Taiwan should construct an integrated platform for precision healthcare that combines the NHI medical database and biological information from Taiwan’s 35 biobanks to reduce cost of precision health. **(2) Align cross-border data transfer regulations and systems with global protocols and infrastructures.** It is critical to share valuable data with global partners for learning together and developing timely solutions for fighting against any diseases with harmonization of standards and regulations among biological databases. **(3) Establish an innovative and flexible ICT ecosystem for precision health.** Taiwan’s long-standing comparative advantages in the ICT industry should be applied to developing biomedical integration technology products and creating innovative diagnostics and therapies. The ICT industry and AI applications of Taiwan are well developed and are sufficient to establish relevant research. For instance, data can be processed with 5G, AI, cloud computing, and other digital technologies such as wearable devices. Telemedicine also has potential to address data sharing and communications issues. Thus, we suggest that the Taiwanese government should support

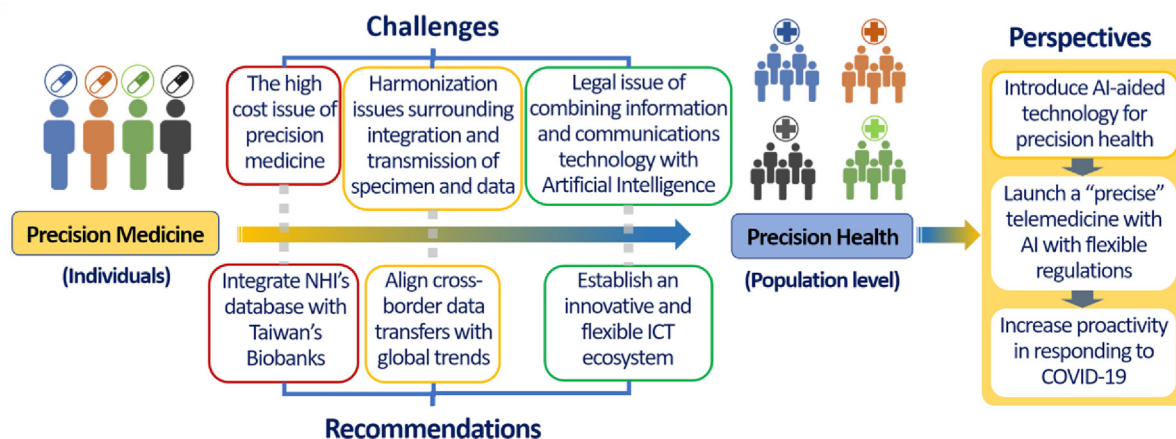


Fig. 5. Proposed framework of precision health: a stepping-stone of precision medicine.



and establish an integrated platform and ICT ecosystem, and also legislate forward-looking and flexible regulations. **(4) Introduce AI-aided technology for precision health.** In the future, the global medical industry will be inseparable from AI. However, even though AI has made it possible to obtain detailed case histories and vast amounts of patient information, its applications should be under the supervision of experienced physicians. **(5) Launch a “precise” telemedicine with AI with flexible regulations.** Launching a precise telemedicine with AI delivers integrated precision health as an application. In 2021, CEOWORLD magazine published the health care guidelines for global medical systems. In this publication, Taiwan was ranked second out of 89 countries in the world based on factors that contribute to improving overall health [44]. Thus, if a precise telemedicine program can be launched, it will help many patients to access health care. **(6) Increase proactivity in responding to COVID-19.** During the COVID-19 pandemic, healthcare data regarding patients at highest risk of hospitalization, intensive care unit admission, death rate could be used for precision health in the fight against the pandemic [45]. In addition to prevent the spread of new diseases effectively and proactively, precision health systems should be improved to help in times of novel health hazard and help prevent economic and social disruption. In summary, it is hoped that precision medicine can serve as a stepping-stone in the transition to precision health. We believe that this is a key role to taking more proactive and personalized solutions to health problems in a way that does not stretch the budget of healthcare systems and public or private insurers, or compromise patients’ ability to access high-quality care. This would make the tools and technologies of precision medicine available to more people. Improving preventative diagnostics at the population level would also serve to improve the quality of healthcare while reducing its overall cost.

## 5. Ethical compliance

The underlying work is based on systematic reviews of published data and thus does not require ethical review approval.

## 6. Data sharing

No additional data available.

## CRedit authorship contribution statement

**Wesley Wei-Wen Hsiao:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Jui-Chu Lin:** Conceptualization, Investigation, Writing – review & editing, Supervision, Funding acquisition. **Chien-Te Fan:** Conceptualization, Investigation, Writing – review & editing. **Saint Shiou-Sheng Chen:** Conceptualization, Investigation, Writing – review & editing, Supervision.

## 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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