Research Article

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Personalized Medicine

Research and innovation in personalized medicine: a descriptive synthesis of actors in the EU and China

Francesco Andrea Causio[‡,1], Ilda Hoxhaj[‡,1,2], Flavia Beccia*[,1], Marzia Di Marcantonio[3], Timo Strohäker[4], Chiara Cadeddu[1], Walter Ricciardi[1] & Stefania Boccia[1,5]

[1]Department of Life Sciences and Public Health, Section of Hygiene, Università Cattolica del Sacro Cuore, Rome, 00168, Italy
[2]Department of Surgery Oncology and Gastroenterology, University of Padova, Padova, 35122, Italy
[3]Faculty of Economics, Università Cattolica del Sacro Cuore, Rome, 00168, Italy
[4]Steinbeis Europa Zentrum, Stuttgart, 70176, Germany
[5]Department of Woman and Child Health and Public Health, Fondazione Policlinico Universitario A Gemelli IRCCS, Rome, 00168, Italy
*Author for correspondence: Tel.: +39 06 3015 4396; flavia.beccia01@icatt.it
‡Authors contributed equally and share first authorship

Aim: Research and innovation (R&I) actors are fundamental in shortening the translational gap of personalized medicine in health systems. In the context of the 'Integrating China in the International Consortium for Personalized Medicine' project, we aimed to map the current landscape of R&I actors in the field of personalized medicine in the EU and China. **Methods:** A two-phase desk research study was conducted. **Results:** We identified 78 R&I actors. Research and technology organizations were the most frequent in both the EU and China. The identified R&I actors were active in a wide range of fields. The EU and China have many different R&I actors addressing personalized medicine-related issues, with few characteristics in common. **Conclusion:** More efforts are needed to ensure these R&I actors are encouraged to work together to bridge each other's gaps.

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Personalized medicine is defined as a medical model that aims to provide tailor-made prevention and treatment strategies for defined groups of individuals, using characterization of individuals' phenotypes and genotypes to tailor the right therapeutic strategy for the right person at the right time and/or to determine the predisposition to disease and/or to deliver timely and targeted prevention [1]. This model has a great potential for the transformation of health systems and improvement of public health, driven by scientific discoveries and technological advances that have enabled its adoption in numerous areas of clinical practice [2,3].

However, these promising premises pose several challenges during the implementation process, particularly the so-called 'translational gap' regarding the low number of newly discovered drugs and technologies that make it to the market. The translation period from research to market and clinical practice is approximately 17 years [4]. Challenges surrounding development, investment, testing and market approval may trigger a vicious circle discouraging innovation itself, with a negative impact on healthcare. Therefore the activity of research and innovation (R&I) actors in personalized medicine, accelerating the process of turning basic research innovation into clinical practice, becomes crucial to reducing the translational gap. For their actions to be effective, policies and programs should provide support at the institutional, national and international levels.

To this end, the International Consortium for Personalized Medicine plays a pivotal role in initiating and supporting innovation and personalized medicine research, funding and implementation [5]. As a coordination and support action within this consortium, the 'Integrating China in the International Consortium for Personalized Medicine' (IC2PerMed) project seeks to create a preferential exchange condition between the EU and China, regions which are both active in supporting innovation within their jurisdictions [6,7]. Specifically, the project aims

to create a roadmap for personalized medicine implementation across the two regions, fostering and sharing best practices and aiding in overcoming barriers [8]. The present work, developed within IC2PerMed, aims to provide an overview of the current landscape of R&I actors in the field of personalized medicine, providing a general perspective, both in the EU and in China, to better address future policymaking efforts and foster Sino-European collaborations.

Materials & methods

Definitions

Given that we could not find a common acknowledged definition of 'R&I actors' to adopt, we considered an eligible actor to be any stakeholder involved in R&I in the field of personalized medicine, both public and private, as well as consortia and entities working to facilitate networking between stakeholders and translation of innovation to the market and clinical practice. Universities and hospitals were not included in the work, whereas academic spin-offs and institutions having a connection with universities were included. Private firms and start-ups were classified as 'small and medium-sized enterprises' (SMEs); state organizations and entities whose governance is mostly public were classified as 'public institutions' (PIs); finally, health clusters and organizations operating exclusively on research were classified as 'research and technology organizations' (RTOs). We decided not to include universities, research hospitals or large private entities (i.e., those employing more than 250 people, by European definition), which were not included because of their dominating role in the sector and different funding mechanisms.

Search strategy

A two-phase desk research was performed to identify relevant documents regarding R&I actors in the field of personalized medicine in the EU and China, published up to January 2022. We included the UK in our search because it was still an EU member state when the IC2PerMed project started. The methodology is reported in detail in the publicly available Deliverable D1.2 of IC2PerMed entitled 'Map of major funding agencies and stakeholders in Europe and China' [6].

Firstly, we performed a gray literature search on the Google search engine to identify relevant documents regarding R&I actors in the field of personalized medicine, using 'research', 'innovation', 'actors', 'initiatives' and 'personalized medicine' as key search terms.

Secondly, we expanded the mapping by web-screening institutional repositories at the level of the EU, such as the EU Commission and Council, EU member states' health ministries and the Ministry of Science and Technology of the People's Republic of China, and additional institutions related to public health in all the countries considered.

The search was carried out in the English and Chinese languages, and no other restrictions were applied. A database with the identified documents was created in Microsoft Excel® (Microsoft Corp., WA, USA); subsequently, the following data were extracted: institution or actor, country, and a link to their website. A descriptive synthesis for each actor is presented below, grouped into two categories for the EU and China, respectively. The search lasted for as long as needed to identify at least one entity per country, including all eligible entities that were found in the meantime.

Results

A total of 78 R&I actors in the EU and China were retrieved, ranging from large PIs to RTOs and SMEs having a specific focus on one single issue related to personalized medicine.

Research & innovation actors in the EU

In the EU, 63 R&I actors were identified which focus on the research and translation process of medical technologies by considering specific needs and providing possible practical solutions. RTOs were the most frequent (n = 47; 75%), while SMEs (n = 9; 14%) and PIs (n = 7; 11%) together accounted for one-quarter of total identified actors (Table 1).

Each one gathers specialist competencies, technologies and resources, whose purpose is setting new standards of care, implementing the clinical practice and enabling the use of digital health, finalized as a better integration of personalized medicine in medical practice. Nonetheless, these R&I actors are collaborating with additional stakeholders, such as government agencies, hospitals, universities and academic institutions.

The country with the most identified R&I actors was Germany (n =11). For several countries, our research only resulted in the identification of one R&I center, and no R&I actors were retrieved for the Czech Republic, Hungary, Latvia, Malta, Portugal or Slovakia.

In Austria, the Austrian Institute of Technology (https://www.ait.ac.at/en/about-the-ait) is the country's largest RTO and is specialized in the research and development of key infrastructures for the future. It is a relevant example of public–private partnership, as the Republic of Austria and the Federation of Austrian Industries own almost equal shares in the institute. The Medical University of Vienna's Center for Precision Medicine (https://www.zpm.at/de), not finished yet, is intended to be one of the leading centers for research and development of treatments in this field. The Ludwig Boltzmann Institute Applied Diagnostics (https://www.applied-diagnostics.at) is a translational research institution that aims to combine a team of transdisciplinary scientists and academic and industrial partners from several countries. It focuses on the development of noninvasive diagnostic methods linking molecular epigenetic and genetic signatures with molecular imaging biomarkers for Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET) analysis while following a dual biomarker concept for tumor diagnosis. Human.technology Styria GmbH (https://www.humantechnology.at) is an association bringing together partners that are active in the field of personalized medicine doing process development, industrial biotechnology, active pharmaceutical ingredients (APIs) development and analysis, flow chemistry and continuous production, as well as biomarker research for therapeutics.

Belgium hosts the Innovative Medicines Initiative (https://www.imi.europa.eu), the world's biggest public–private partnership in life sciences, between the European Commission and the European Federation of Pharmaceutical Industries and Associations. Sciensano (https://www.sciensano.be/en/about-sciensano) is a research institute and the national public health institute of Belgium. It was established in 2018 and works on several health programs following the 'One Health' principle: among these, there are advanced molecular diagnostics in cancer aiming at improving diagnosis, prognosis and treatment. To streamline the introduction of next-generation sequencing in the healthcare system, Sciensano outlined a 5-year program in the 'Roadbook: Personalized medicine: the introduction of next-generation sequencing in routine diagnostics in oncology and hemato-oncology (2016–2020)' [9]. The Personalized Medicine Commission (https://www.compermed.be/en/) is a committee bringing together Belgian scientific expertise in this area. It aims to develop technical guidelines to permit quality assurance for the molecular tests (specifically next-generation sequencing tests) used in oncology and hemato-oncology, while also defining molecular biomarkers and good clinical practice in routine clinical practice.

In Bulgaria, Digital Health and Innovation Cluster Bulgaria (https://dhicluster.bg/?lang=en) is a non-profit association that supports companies and organizations in the field of digital solutions and innovations in healthcare to build an ecosystem and establish a sustainable and effective healthcare environment for patients, healthcare professionals, society and institutions.

Croatia's Genos (https://genos-glyco.com) is the leading laboratory for glycomics in the world, offering high-throughput glycan analysis and other commercial services for analytical chemistry to study design and statistical data analysis.

Cyprus's Computation-based Science and Technology Research Center (https://castorc.cyi.ac.cy/about/castorc-overview) pioneers the introduction, development and employment of intense computational methods and data to advance scientific and technological disciplines, aspiring to cultivate the use of high-performance computing and data science in Cyprus and the eastern Mediterranean and to serve the needs for computational and data-intensive applications.

In Denmark, Digital Hub (https://digitalhubdenmark.dk/) brands home-grown digital solutions to attract talent, investments and international customers to new scalable health tech products and services that are shaping future industries worldwide. Biopeople (http://www.biopeople.dk) is a life science cluster affiliated with the Faculty of Health and Medical Sciences at the University of Copenhagen; it is funded by the Ministry for Science and Higher Education to improve innovation, collaboration and education within the National Danish Innovation System.

The North Estonia Medical Center (https://tai.ee/en) is a regional hospital providing high-quality specialized medical care and ambulance services, providing a learning base of training that both precedes and follows the acquisition of healthcare professionals' qualifications and does healthcare-related study and research work.

The Finnish Institute for Molecular Medicine (https://www.fimm.fi) is a translational research institute, focusing on human genomics and precision medicine, under the umbrella of the Helsinki Institute of Life Science at the University of Helsinki, whose driving mission is to perform innovative research on patients and populations targeted toward understanding drivers of health and disease.

In France, Genopole (https://www.genopole.fr) is a research center in Évry-Courcouronnes focused on biotherapies, genetics, genomics, post-genomics, xenobiology and the development of biotechnology industries, uniting innovative high-tech life sciences companies, public and private research and higher education facilities. Eurobiomed (https://www.eurobiomed.org/en/) is a competitiveness cluster bringing together an ecosystem of more than 400 players with different expertise and working on developing and marketing innovative products and services to generate growth and jobs in the field of personalized medicine.

In Germany, the Heidelberg Center for Personalized Oncology (https://www.dkfz.de/en/hipo/) focuses on three areas of expertise – namely, genome analysis, computational biology and precision oncology – to translate the latest research and technologies from the 'omics' fields (genomics, transcriptomics etc.) and systems biology/medicine into clinical practice. The Center for Personalized Medicine (https://uni-tuebingen.de/en/64728) connects the diverse aspects of data production, data analysis, functional imaging, development of new therapies and related clinical trials to transfer the innovation into clinical care. Together with the medical faculty, the University Hospital and the University of Tübingen, the center has launched different research projects, qualified to generate individual patient-derived data, integrate comprehensive data and analyze highly complex biological information. The overall goal of their efforts is the precise description of complex diseases to find new approaches for innovative therapies. The Berlin Institute of Health (https://www.bihealth.org/en) is a biomedical research institution focusing on translational research and precision medicine, dedicated to improving the prediction of progressive diseases and developing advanced therapies for unmet medical needs to improve patients' health and quality of life. The HealthCapital–Healthcare Industries Cluster Berlin–Brandenburg (https://www.healthcapital.de) drives networking and technology transfer in the region and supports international companies in the fields of drug development, diagnostics, regenerative medicine, glycobiotechnology and industrial biotechnology, among others. The Cluster for Individualized Immune Intervention (https://ci-3.de) is a non-profit organization that has the aim of promoting the advancement of personalized medicine and individualized immunotherapies, facilitating collaboration between academia, SMEs, large corporations, regulators and the public. BioLAGO (https://www.biolago.org/en/) is a cross-border health network in the four-country region of Lake Constance (Germany, Switzerland, Austria and Liechtenstein) which links business and science for innovation and addresses the high-tech sectors of the healthcare industry, including personalized medicine, medical technology, diagnostics, bioinformatics and pharmaceuticals. BioRN (https://www.biorn.org) is a non-profit network fostering health innovations, supporting a rich translational ecosystem and offering tailored scouting services for partners. BioPark Regensburg GmbH (https://www.biopark-regensburg.de) is an enterprise promoting biotechnology, medical engineering, diagnostics and analytics as well as healthcare, with a focus on the local level. BioM (https://www.bio-m.org) brings together biotechnological and pharmaceutical companies active in the development of innovative therapeutics and diagnostics, in particular for personalized healthcare. BioCon Valley® GmbH (https://www.bioconvalley.org/) is a network of industries active in networking and industry monitoring, project initiation and support, internationalization and marketing in the healthcare sector. BioRegio STERN Management GmbH (https://www.bioregio-stern.de) supports companies from the diagnostics, medical equipment development and manufacturing, prosthetics, implants and medical electronics sectors, fostering joint research and development projects.

In Greece, the Biomedical Research Foundation of the Academy of Athens (http://www.bioacademy.gr) hosts both basic and clinical research, recruiting high-quality investigators for cutting-edge basic and translational research. The Biomedical Sciences Research Center 'Alexander Fleming' (https://www.fleming.gr) is a non-profit research organization focusing on scientific and technological excellence, training and innovation in biomedical sciences. The Hellenic Pasteur Institute (https://www.pasteur.gr/en), established in 1920, directs its research to the prevention and treatment of diseases through basic research, education and public health services. The institute traditionally focuses on infectious diseases but also investigates autoimmune, neurodegenerative and neuromuscular disorders and certain types of cancer. The Hellenic Digital Health Cluster (http://www.hdhc.gr) brings together Greek companies that are active in the field of digital health to support their development and innovation.

In Ireland, the Connected Health and Wellbeing Cluster (https://www.chwcluster.ie) encourages and facilitates collaboration between industry, academia, healthcare providers and enterprise support agencies.

In Italy, the National Research Council (CNR) (https://www.itb.cnr.it) is the primary government agency with the task of fostering exceptional basic biomedical and clinical research through intramural and extramural programs. Within the CNR, the National Institute of Biomedical Technologies derives from the merger of different institutes and units of the CNR. TecnoMED Puglia (https://www.tecnomedpuglia.it/en) is a technopole for precision

medicine in Lecce, at the Institute of Nanotechnology NANOTEC-CNR, focusing on translational medicine. Toscana Life Sciences (https://www.toscanalifesciences.org/en/) is a non-profit organization active throughout the region in supporting research activities and promoting the creation of innovative companies in the life sciences field. The Clust-ER Health – Emilia-Romagna (https://health.clust-er.it/) is an association consisting of large companies, SMEs, laboratories of the high technology network, research centers, health facilities and training institutions that share skills, ideas and resources to support the competitiveness of the health and wellness industries of Emilia-Romagna.

Lithuania's I-Vita cluster (https://www.nvi.lt/en/) connects innovative organizations in the field of healthcare, with management and technical potential that puts a strong base for rich business-oriented activities toward higher competitiveness and further expansion.

In Luxembourg, Clinnova (https://digital-luxembourg.public.lu/news/clinnova-new-luxembourg-centre-excellence-digital-health-and-personalised-medicine) is a center of excellence in digital health and personalized medicine whose aim is to ensure effective implementation of lab innovation in the clinic and patient care. The Laboratoire National de Santé (https://lns.lu/en) is a PI operating under the supervision of the Ministry of Health in Luxembourg, working in the fields of morphological and molecular pathology and genetics, medical biology, microbiology, forensic medicine and health protection. The Luxembourg Center for Systems Biomedicine (https://wwwen.uni.lu/lcsb) supports biomedical research by closing the gap between systems biology and medical research. Bringing together biologists, medical doctors, computer scientists, physicists, engineers and mathematicians, it offers new insights into complex systems like cells, organs and organisms. Its vision is to understand the mechanisms of complex biological systems and disease processes and to enable new ways to cure and prevent human diseases. The Luxembourg HealthTech Cluster (https://www.luxinnovation.lu/cluster/luxembourg-healthtech-cluster) brings together different players involved in innovative health technologies, aiming to promote the development of new and existing companies through innovation. It strives to capitalize on the country's advanced digital expertise to stimulate the development and commercialization of health technologies, supporting the development of sustainable and trusted services and products aimed at the European healthcare market in fields such as digital health, medical devices and software.

In The Netherlands, LifetecZONe (https://www.lifeteczone.nl) is a network for entrepreneurs in life sciences and medical technology, bringing together SMEs and knowledge institutions, healthcare providers, governments and organizations in and outside the southern Netherlands. Health Valley (https://www.healthvalley.nl) is a healthcare innovation network in the east of The Netherlands, working in close contact with healthcare institutions, knowledge institutions, the business community and governments as partners, bringing public and private parties together and accelerating innovation through the use of technology.

In Poland, Warsaw Genomics (https://warsawgenomics.pl/en) develops and delivers highly sensitive and accurate evidence-based genetic tests, applying cutting-edge genetic analysis tools and using proprietary algorithms for genetic diagnosis. The Lublin Medicine Medical and Wellness Cluster (https://medycyna.lublin.eu) is a cooperation platform used by higher education institutions, research centers, healthcare entities, entrepreneurs, institutions for collaboration and local authorities to support the development of local medical and wellness industries.

In Romania, the innovative cluster 'Pentru Sănătate Dunărea de Jos' ('For the Health of the Lower Danube'; https://clustersanatate.ro) provides training and support to its beneficiaries, such as education support, assistance in European funding access and translation to market. The North East Regional Innovative Cluster for Structural and Molecular Imaging Imago-Mol (https://www.imago-mol.ro) is a non-governmental, non-profit organization whose objectives are to support the growth of scientific competitiveness of its members and the economic competitiveness of northeastern Romania in the field of medical imaging, by developing a framework for cooperation targeting diversification and optimization of services in this specific area.

In Slovenia, the Slovenian Innovation Hub (https://sis-egiz.eu) offers support to strategic innovation partnerships in the priority area of Slovenia's smart specialization strategy (i.e. health and medicine). It is a service for connecting and networking with individual stakeholders, companies, research organizations, technology centers and value chains. and allows innovators to reach global markets in the areas of translational medicine, biopharmaceuticals, herbal medicine and natural cosmetics, cancer treatment therapies and active and healthy living.

In Spain, the Center for Genomic Regulation (https://www.crg.eu/en) is a non-profit international biomedical research institute of excellence, created in July 2000 and funded by the Catalan government. The Health Services Research on Chronic Patients Network (https://www.redissec.com/en) is committed to developing excellence in the fields of research, development and innovation, and to providing evidence on best practices and organizations,

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with the aim of improving the results of the healthcare provided to chronically ill patients in Spain and increasing research capacity in health policies and services in Spain. The Roche Institute Foundation (https://www.institutoroche.es/) aims to anticipate and transfer knowledge about precision/personalized medicine in order to contribute to Spain being at the forefront of health innovation. Ticbiomed (https://ticbiomed.org/) is a business association that promotes collaborative projects in digital health, facilitating open innovation agreements between different eHealth stakeholders. Biocat (https://www.biocat.cat) brings together the life sciences and healthcare innovation communities in Catalonia, raising awareness and promoting the ecosystem, creating tools and strategies for improving knowledge of the Catalan healthcare sector and increasing its projection both at home and abroad, to position the 'BioRegion' as an international reference center. The Cluster Saudé Galicia (https://clustersaude.com) works as a communication platform for its members and is subdivided into three councils: health, industry and social policy. BIOGA 'Cluster Tecnolóxico Empresarial das Ciencias da Vida' ('Business Technology Cluster of Life Sciences'; https://www.bioga.org) is a for-profit business organization that brings together integrated organizations in the biotechnology sector that have their headquarters in Galicia. The Basque Foundation for Innovation and Health Research (http://www.biobancovasco.org/), established by the Department of Health of the government of the Basque Country, is a support instrument for the health authorities of the country. Its mission is to promote innovation and research in the Basque health service, to foster innovation and to improve the quality of the health system. The foundation seeks to provide collaboration, cooperation and communication between development and health innovation actors at regional, national and international levels.

Sweden's Science for Life Laboratory (https://www.scilifelab.se) is an institution for the advancement of molecular biosciences in Sweden, started in 2010 as a joint effort between the Karolinska Institutet, Kungliga Tekniska högskolan (KTH) Royal Institute of Technology, Stockholm University and Uppsala University. Vinnova (https://www.vinnova.se) is the Swedish government's innovation agency, which is active on personalized medicine initiatives at national and European levels and involves stakeholders at different levels.

In the UK, the Cell and Gene Therapy Catapult (https://ct.catapult.org.uk) is a center of excellence in innovation, with the core purpose of building a world-leading cell and gene therapy sector in the UK as a key part of a global industry. Supported by Innovate UK, its mission is to drive the growth of the industry by helping cell and gene therapy organizations across the world translate early-stage research into commercially viable and investable therapies. The Wales Gene Park (http://www.walesgenepark.cardiff.ac.uk) aims to support the implementation of the Welsh government's 'genomics for precision medicine' strategy by promoting and facilitating high-quality genetic and genomic health research in Wales. It does this by ensuring seamless translation of advances in genetics and genomics to improve National Health Service interventions and for commercialization, as well as guaranteeing the informed involvement of patients, the public and professionals in the development of genomic medicine in Wales. The Wellcome Sanger Institute (https://www.sanger.ac.uk) is one of the premier centers of genomic discovery and understanding in the world, seeking to share its discoveries and techniques with the next generation of genomics scientists and researchers worldwide.

Research & innovation actors in China

With regard to China, the mapping identified 15 R&I actors in different regions of the country. PIs (n = 7; 47%) and RTOs (n = 7; 47%) were the most frequent, with a single SME (n = 1; 7%) found among all identified actors (Table 2).

The Municipality of Beijing hosts the majority of the actors, including the Beijing Institute of Genomics (http://english.big.cas.cn), which is considered the key genomic science and information laboratory of the Chinese Academy of Sciences, working on the integration of biological big data, intergenerational inheritance and epigenome reprogramming. The Chinese Society of Clinical Oncology (http://www.csco.ac.cn) is a non-profit public professional academic group founded in 1997 and formed by clinical oncology operators and related businesses and institutions. It has long been engaged in continuous clinical oncology training and multicenter collaborative research, performing research on precision medicine. Genetron Health (https://en.genetronhealth.com) is a leading and fast-growing precision oncology company in China that is committed to providing multi-scenario genomic profiling solutions in areas including early cancer screening, diagnosis and monitoring as well as biopharmaceutical services. It has three other offices in China: Shanghai, Chongqing and Guangzhou. The National Administrative Center for China's Agenda 21 (http://www.acca21.org.cn/), established in 1994, is a public institution promoting the country's sustainable development in medical science and technology, building on scientific and technological progress to promote sustainable development as well as developing a range of strategies and policies in the field.

BGI (https://en.genomics.cn/en-about.html), formerly known as the Beijing Genomics Institute, is among the world's leading life science and genomics organizations, providing equipment, technical support and solutions for the needs of national economies and people's livelihoods, such as precision medicine and precision health.

Located in Guandong, the National Cancer Center, Cancer Hospital of the Chinese Academy of Medical Sciences (http://www.cicams.ac.cn/) is an institute supported by the Cancer Hospital of the Chinese Academy of Medical Sciences, a national research center of cancer clinical medicine, which is a combination of hospital, education, research and prevention, focusing on basic research and clinical treatment regarding cancer. The Institute of Precision Medicine and Health (https://www.ipm-gba.org.cn/) was founded in 2017 and has eight research centers: Ferid medicine research center, Marshall precision medical treatment of gastric disease research center, Dmitri precision medical treatment research center, Joseph wearable sensors research center, Robert drug research center, accurate diagnostic medical research center, Medical and health research center and Nanomedicine research center. It carries out cutting-edge international research, aiming at bringing the results to clinical practice. The Sun Yat-sen University Cancer Center (https://www.sysucc.org.cn) was established in March 1964 and integrates medical treatment, teaching, scientific research and translation of basic research into clinical practice. The Guangzhou Institute of Biomedicine and Health of the Chinese Academy of Science (http://english.gibh.cas.cn) provides an excellent research and development platform in biomedicine and functions as an incubator for bioengineering and pharmaceutical industries to support local economic development as well as national strategic science and technology programs. The Greater Bay Area Institute of Precision Medicine (https://www.ipm-gba.org.cn/Index/cooperation/cid/15.html) builds on the scientific research advantages of Fudan University and is focused on the frontier fields of precision medicine, carrying out and applying relevant basic research, technology research and transformation. Similarly, Huaqiao University's Center of Precision Medicine (https://en.hqu.edu.cn), established in December 2017, is mainly focused on research into the pathogenesis of neurological and psychiatric diseases, exploring molecular markers for disease diagnosis and treatment.

Located in the Municipality of Shanghai is the Shanghai Institute of Precision Medicine (http://www.shipm.cn/jyjz_web/html/jyjz_English/portal/index/index.htm), which was established in 2017 and focuses on basic research and translational research; it has six cutting-edge research facilities in the fields of protein engineering, mass spectroscopy, electron microscopy, bio-imaging, chemical biology and bioinformatics. The State Key Laboratory of Genetic Engineering (http://geneticengine.fudan.edu.cn/) is a research entity focused on the occurrence and impact of genetic variation, based on systematic genetic and genetic engineering research.

The Municipality of Chongqing hosts the Cancer Precision Medicine Research Center (https://en.cqch.cn), which belongs to the School of Medicine of Chongqing University. It integrates basic research, translation and clinical application into tumor molecular diagnosis and precise tumor prevention and treatment, focusing on tumor biology.

Discussion

This work aimed at identifying major R&I actors in the field of personalized medicine in the EU and in China, each of which is giving a unique contribution to performing basic research and bringing innovations to market. The personalized medicine ecosystem is a complex one, where many players have overlapping competencies and intersections, resulting in an environment where it is often difficult to find a way. However, Europe and Asia are the best-performing regions in the field of governance, given the implementation of policy frameworks for personalized medicine implementation and existing governmental support, allowing actors to flourish [10].

Our mapping shows that both the EU and China contain many different actors active in R&I in personalized medicine; they are unique in addressing the many challenges posed by personalized medicine, but have few characteristics in common. Several actors are active in so-called 'basic research', thanks to the progress of technology and the vast amount of data and research papers available in recent years, proving that this sector is flourishing despite challenges raised by the increased attention toward preclinical research [11].

Many of the identified actors are active in the development of new medical technologies, aiming to translate the results of basic research to the bedside of the patient. These centers are of the utmost importance to close the translational gap that keeps most of the findings in basic research from the clinical arena, for patients' benefit and use. Because of the many factors influencing the translatability of basic research to the industry, these actors are important in taking on the risk of experimenting and trying to develop new technologies using findings from the research institutions [12].

Table 1. Research and innovation actors in personalized medicine in the EU.

Institution	Country	Website	Type of entity
Austrian Institute of Technology	Austria	https://www.ait.ac.at/en/about-the-ait	RTO
Center for Precision Medicine	Austria	https://www.zpm.at/de	RTO
Ludwig Boltzmann Institute Applied Diagnostics	Austria	www.lbiad.lbg.ac.at	RTO
Human.technology Styria GmbH	Austria	https://www.humantechnology.at	SME
Innovative Medicines Initiative	Belgium	https://www.imi.europa.eu	RTO
Sciensano	Belgium	https://www.sciensano.be/en/about-sciensano	PI
The Personalized Medicine Commission (ComPerMed)	Belgium	https://www.compermed.be/en/	RTO
BioWin	Belgium	https://biowin.org	RTO
Lifetech.brussels	Belgium	https://lifetechbrussels.com	RTO
Digital Health and Innovation Cluster Bulgaria	Bulgaria	https://dhicluster.bg/?lang=en	RTO
Genos	Croatia	https://genos-glyco.com	SME
Computation-based Science and Technology Research Center	Cyprus	https://castorc.cyi.ac.cy/about/castorc-overview	PI
Digital Hub	Denmark	https://digitalhubdenmark.dk/	RTO
Biopeople	Denmark	http://www.biopeople.dk	RTO
The North Estonia Medical Center	Estonia	https://tai.ee/en	PI
Institute for Molecular Medicine Finland	Finland	https://www.fimm.fi	RTO
Genopole	France	https://www.genopole.fr	RTO
EUROBIOMED	France	https://www.eurobiomed.org/en/	SME
Heidelberg Center for Personalized Oncology	Germany	https://www.dkfz.de/en/hipo/	RTO
Center for Personalized Medicine, Tübingen	Germany	https://uni-tuebingen.de/en/64728	RTO
Berlin Institute of Health	Germany	https://www.bihealth.org/en	RTO
HealthCapital – Cluster Healthcare Industries Berlin Brandenburg	Germany	https://www.healthcapital.de	RTO
Cluster for Individualized Immune Intervention	Germany	https://ci-3.de	RTO
BioLAGO	Germany	https://www.biolago.org/en/	RTO
BioRN – Life Science Cluster Rhine–Neckar	Germany	https://www.biorn.org/	RTO
BioPark Regensburg	Germany	https://www.biopark-regensburg.de	SME
BioM Biotech Cluster Development GmbH	Germany	https://www.bio-m.org/	SME
BioCon Valley® GmbH	Germany	https://www.bioconvalley.org/	SME
BioRegio STERN Management GmbH	Germany	https://www.bioregio-stern.de/en/projects/plan-of-action-for-medical-technology	SME
Biomedical Research Foundation of the Academy of Athens	Greece	http://www.bioacademy.gr	RTO
Biomedical Sciences Research Center 'Alexander Fleming'	Greece	https://www.fleming.gr	RTO
Hellenic Pasteur Institute	Greece	https://www.pasteur.gr/en	RTO
Hellenic Digital Health Cluster	Greece	http://www.hdhc.gr	RTO
Connected Health and Wellbeing Cluster	Ireland	https://www.chwcluster.ie	RTO
The National Research Council	Italy	https://www.itb.cnr.it	PI
TecnoMED Puglia	Italy	https://www.tecnomedpuglia.it/en	RTO
Tuscany Life Sciences Cluster	Italy	https://www.toscanalifesciences.org/en/	RTO
Clust-ER Health, Emilia-Romagna	Italy	https://health.clust-er.it/en/	RTO
Health technology cluster iVita	Lithuania	https://www.i-vita.lt/	RTO
Clinnova	Luxembourg	https://www.clinnovaresearch.com/	RTO
Laboratoire National de Santé	Luxembourg	https://lns.lu/en/	PI
Luxembourg Center for Systems Biomedicine	Luxembourg	https://wwwen.uni.lu/lcsb	RTO
Luxembourg HealthTech Cluster	Luxembourg	https://www.luxinnovation.lu/cluster/luxembourg-healthtech-cluster	RTO
LifetecZONe	The Netherlands	https://www.lifeteczone.nl	RTO
Health Valley	The Netherlands	https://www.healthvalley.nl	RTO

PI: Public institution; RTO: Research and technology organization; SME: Small or medium-sized enterprise.

Table 1. Research and innovation actors in personalized medicine in the EU (cont.).

Institution	Country	Website	Type of entity
Warsaw Genomics	Poland	https://warsawgenomics.pl/en/#!	SME
Lublin Medicine Medical and Wellness Cluster	Poland	https://medycyna.lublin.eu	RTO
Innovative Cluster 'Pentru Sănătate Dunărea de Jos'	Romania	https://clustersanatate.ro/	RTO
North-East Innovative Regional Cluster for Structural and Molecular Imaging	Romania	https://www.imago-mol.ro/?lang=en	RTO
Slovenian Innovation Hub, European Economic Interest Grouping	Slovenia	https://sis-egiz.eu	RTO
Center for Genomic Regulation	Spain	https://www.crg.eu/en	RTO
Health Services Research on Chronic Patients Network	Spain	https://www.redissec.com/en	RTO
Roche Institute Foundation	Spain	https://www.institutoroche.es/	RTO
Ticbiomed	Spain	https://ticbiomed.org	RTO
Biocat (Bioregion of Catalonia)	Spain	https://www.biocat.cat	PI
Cluster Saudé Galicia	Spain	https://clustersaude.com	RTO
BIOGA Cluster Tecnolóxico Empresarial das Ciencias da Vida	Spain	https://www.bioga.org	RTO
Basque Foundation for Innovation and Health Research	Spain	http://www.biobancovasco.org/	RTO
Science for Life Laboratory	Sweden	https://www.scilifelab.se	RTO
Vinnova	Sweden	https://www.vinnova.se	RTO
Cell and Gene Catapult	UK	https://ct.catapult.org.uk	SME
Wales Gene Park	UK	http://www.walesgenepark.cardiff.ac.uk	PI
Wellcome Sanger Institute	UK	https://www.sanger.ac.uk	RTO

PI: Public institution; RTO: Research and technology organization; SME: Small or medium-sized enterprise.

Table 2. Research and innovation actors in personalized medicine in China.

Institution	Region	Website	Type of entity
Chinese Society of Clinical Oncology	Beijing	http://www.csco.ac.cn/	RTO
Beijing Institute of Genomics	Beijing	http://english.big.cas.cn/	RTO
BGI	Beijing	http://en.genomics.cn/en-about.html	RTO
Genetron Health	Beijing	https://www.genetronhealth.com	SME
National Cancer Center, Cancer Hospital of Chinese Academy of Medical Sciences	Beijing	https://ancca.asia/ncc/2/China	PI
National Administrative Center for China's Agenda 21	Beijing	http://www.acca21.org.cn/trs/000100020001/	PI
Institute of Precision Medicine and Health (IPMH)	Guandong	https://en.ustb.edu.cn/research/research_institute/10471883.htm	RTO
National Cancer Center, Cancer Hospital of the Chinese Academy of Medical Sciences	Guandong	http://cicasm.ac.cn/	PI
Sun Yat-sen University Cancer Center	Guandong	http://www.sysucc.org.cn	PI
Guangzhou Institute of Biomedicine and Health of the Chinese Academy of Science	Guandong	https://english.gibh.cas.cn	PI
Greater Bay Area Institute of Precision Medicine	Guangzhou	http://ipmm-gba.org.cn/Index/cooperation/cid/15.html	RTO
Center of Precision Medicine	Guangzhou	http://un.hqu.edu.cn	RTO
Shanghai Institute of Precision Medicine	Shanghai	http://www.shipm.cn/jyjz_English/portal/Index.htm	PI
State Key Laboratory of Genetic Engineering	Shanghai	http://geneticengine.fudan.edu.cn/	PI
Cancer Precision Medicine Research Center	Shanghai	http://en.cqch.cn	RTO

PI: Public institution; RTO: Research and technology organization; SME: Small or medium-sized enterprise.

Another factor leading to the existence of a translational gap is the lack of bridging opportunities, bringing together entities from different branches and competence areas. During our search, it was not possible to find any platform or community giving a comprehensive overview of the R&I actors in personalized medicine in the EU or China, suggesting that a dedicated effort in this direction would be helpful in facilitating interaction between them. It is notable, indeed, how promoting collaboration between different entities would bring important results.

Therefore, to foster collaboration between the EU and China, creating a dedicated network would bring more advantages. It is often difficult to generate significant evidence, often due to the limited amount of data available, the small number of patients affected by a peculiar condition or the 'personalized' nature of the intervention itself [3]. Therefore bringing similar institutions to work together can help them collate the available evidence and produce important results, which would be impossible otherwise. Alternatively, a stronger collaboration between entities of different kinds can lead to reciprocal benefits for both sides; for example, giving feedback on the reproducibility of data to the basic research institutions, while translational institutions could get insights and preliminary results from such closer collaborations. In this context, clusters bringing together different entities and contributing to cross-field cooperation are crucial in helping these parties work together, but the current high fragmentation of the sector requires that more efforts be put toward integration under common guidelines.

The results of this research highlight the heterogeneity of this dynamic and evolving field, with many different stakeholders sharing similar interests and focus points. Yet, it is unusual to find two centers focusing on the same activities, so that in the end every entity is unique.

This work should be considered in light of some strengths and limitations.

To our knowledge, this work represents the first attempt to provide a comprehensive overview of R&I actors in personalized medicine in the EU and in China, mapping and describing them. Trying to overcome the limitations of this kind of review, we conducted extensive desk research, adopting multiple sources and consulting national contact points and experts within the IC2PerMed consortium; however, we do not presume that our work is representative of the entire panorama of R&I actors in this field. Through the search for sources on the web, it is possible that some results were not found because they were not indexed on the most common search engines or not reported on institutional sites, and it is also possible that national-language websites were not identified, because the search was conducted only in English and Chinese. However, by providing a list of actors, we are laying the foundations for facilitating future initiatives aimed at fostering collaboration between entities having different backgrounds. Although our work may not include every active stakeholder in the field, it could be used as a starting point for future initiatives, helping to assess how heterogeneous the players in this field are. Future efforts aimed at bridging the translational gap should keep in mind the heterogeneity of this field: because it is so vast, entities differ in size, goals and operational pathways, each having unique focus and resources.

Tables 1 and 2.

Conclusion

Our work highlights that collaboration between these actors is complicated by stakeholder isolation, lack of a platform bringing them together for collaboration, and overlapping competencies and goals. Nonetheless, it is important that the many aspects in which they differ serve as a starting point for joint projects and policies catalyzing them, ensuring that they address efforts properly rather than proceeding singularly along the way.

Creating preferential pathways for collaboration between EU and Chinese partners can help solve this lack of competencies on core themes, with each providing unique perspectives. Facilitating interaction and synergy would ultimately lead to better use of available resources and improved research outcomes, from which both parties would benefit.

Author contributions

F Causio, I Hoxhaj, F Beccia and M Di Marcantonio were major contributors to the drafting of the manuscript. T Strohäker and C Cadeddu made important contributions and suggestions. W Ricciardi and S Boccia revised the manuscript substantially. All authors read and approved the final manuscript.

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Ethical conduct of research

This study does not involve human participants and ethical approval was not required.

Summary points

Introduction

- Personalized medicine is defined as a medical approach in which prevention and treatment strategies are designed to accommodate the individual needs of specific patient cohorts.
- The potential challenges to the development, infusion, testing and clearance of novel technologies could trigger a deleterious feedback loop that discourages innovation and thus adversely affects healthcare.
- Therefore, initiatives of research and innovation (R&I) entities in personalized medicine to accelerate the transition from basic research and innovation to medical practice are essential in minimizing the translational gap.
- To achieve this goal, the 'Integrating China in the International Consortium for Personalized Medicine' project works to establish a favorable environment for exchanges between the EU and China, which are both investing in fostering innovation through their respective jurisdictions.

Methods

- A two-phase desk research study was conducted to ascertain pertinent English and Chinese documents pertaining to R&I actors in the domain of personalized medicine in the EU and China, released up to January of 2022.
- A gray literature search was conducted, followed by the mapping and screening of European and Chinese institutional repositories, using 'research', 'innovation', 'actors', 'initiatives' and 'personalized medicine' as key search terms.
- A descriptive summary of each actor is provided.

Results

- In total, 78 representatives of R&I actors engaged in policymaking in the EU (n = 63) and China (n = 15) were identified, including a wide range of entities from large public institutions to research and technology organizations and small and medium-sized enterprises.
- Each entity gathers specialist proficiencies, technologies and assets with the intent of establishing novel norms of care, implementing clinical practice and facilitating the use of digital health.
- R&I actors engage with other stakeholders, including governmental authorities, medical facilities, universities and educational establishments.

Discussion

- Both the EU and China have a sizable number of diverse players involved in R&I in personalized medicine, each with a unique strategy for addressing the challenges of personalized medicine but with few things in common.
- Numerous actors are engaged in what is known as 'basic research' as a result of technological advancements and the availability of vast amounts of data or research papers.
- Many of the recognized players are involved in the production of innovative medical technologies to translate the discoveries of basic research to the patient's bedside.
- The importance of these centers lies in their capacity to close the translational divide, enabling many conclusions drawn from basic research to be transferred into patient care.

Conclusion

- It is of utmost significance to foster interaction and collaboration between the EU and China, as these initiatives would lead to more efficient use of resources and more successful research outcomes, benefiting both parties.

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