frontiers | Frontiers in Tropical Diseases

TYPE Opinion
PUBLISHED 18 September 2025
DOI 10.3389/fitd.2025.1653226

OPEN ACCESS

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RECEIVED 24 June 2025
ACCEPTED 03 September 2025
PUBLISHED 18 September 2025

CITATION
Wei Q, Luong JCH, Cheong IH and Kozlakidis Z (2025) The intersectoral challenges facing biobanking in One Health and Global Health. *Front. Trop. Dis.* 6:1653226. doi: 10.3389/fitd.2025.1653226

The intersectoral challenges facing biobanking in One Health and Global Health

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KEYWORDS

biobanking, One Health, Global Health, data integration, standardization

Introduction

Biobanking, defined as the systematic collection of biological samples and associated data under a defined governance framework, has become a foundational activity in medical research, facilitating the development of personalized medicine research through the provision of high-quality, research-ready materials and linked data. Such global frameworks include the ISO20387:Biobanking, the Nagoya protocol, and others (1, 2). Furthermore, biobanking is emerging as a core activity outside of medical research and precision medicine (3) to include animal, plant, environmental and other types of activities that would fall under One Health and Global Health contexts (4, 5). Finally, as several experimental approaches are increasingly based on high-throughput '-omics' technologies, biobanking offers a practical solution to the provision of standardized biological material and data at scale.

However, while biobanks are becoming indispensable to scientific research, they face significant evolving intersectoral challenges across current and long-term horizons (6, 7). These challenges can be more structural, e.g., ageing infrastructure and the need for continuous training of staff as new technologies are introduced, and also operational, e.g., including standardization, data-sharing, interoperability and integration of operations, and others. Furthermore, such challenges can often be magnified in low- and middle-income countries (LMIC), and while the introduction of digital solutions may offer powerful tools for improving the real-time control and efficiency of operations, it can also introduce further complexities relating to power dynamics and access (8, 9). It is the authors' opinion that the most effective way in overcoming such challenges in biobanking, in particular within the One Health and Global Health contexts, lies in the fostering of robust, equitable and collaborative networks. This manuscript provides an overview of the existing and anticipated challenges, as well as a prospective for the way forward.

Current challenges: foundations under strain

The ongoing data collection for banked samples from diverse sources, as is often the case in One Health projects, can lead to a heterogeneous information repository, particularly when various subsets of a biobank's collection are used for different purposes—generating and occasionally returning distinct types of data. We believe that this situation is exacerbated further by the lack of uniform protocols on sample collection, processing, storage, and quality control. Standardization efforts (10) and practical propositions for biological samples storage and use, especially for diverse pathogen sources across environments (e.g., pathogens coming from human or non-human sources, and particularly when the same pathogen is taken from different environments (11, 12)), are addressing these issues. Recording such collections requires the implementation of Laboratory Information Management Systems (LIMS), tracking sample provenance and ensuring quality control (13), reflecting the efforts of standardization from the biological to the digital aspect (14). However, for LMICs, the absence or inaccessibility of robust digital solutions can amplify the standardization challenge, making quality control and adherence to standards more difficult and reverting to the need for manual control. A limited number of projects have attempted to address this latter point, e.g., the European Union (EU)-funded 'Bridging Biobanking and Biomedical Research across Europe and Africa' (B3 Africa), that did create an open-source LIMS biobank software (in a box [BIBOX]) designed from the beginning with LIMC specificities into account (15). In our view, such projects are few and their frequency does not concur with the level of need.

An additional current challenge relates to data-sharing, which encompasses many aspects, whether data is collected for healthcare or environmental research, and is thus impacting biobanking. The regulatory landscape is evolving continuously in response to the technological progress and the possibilities the latter affords. For example, in the EU there has been the introduction of General Data Protection Regulation (GDPR) (16, 17), and globally the Nagoya protocol has been implemented for non-human samples (18). Most recently the World Health Organization (WHO) adopted the Pathogen access and benefit sharing agreement (PABS), which also outlines obligations and expectations in terms of data-sharing for pathogens specifically (19). It becomes clear from the above that the data-sharing functions relating to biobanking in One Health and Global Health are governed by several frameworks at the same time (often overseen by different ministries, e.g., health and agriculture), and this can pose ongoing stresses to such work moving forward. From a technological point of view, there are solutions that can offer adaptation to data-sharing restrictions, such as federated (20) and block-chain approaches (21), however these have not been tested at scale as yet. Lastly, data sharing requires clarity as regards the legal concerns such as intellectual protection, and these have been described in detail (22) though not necessarily addressed in full. Prior experience from such work, e.g., during the zika virus outbreak (23), exposed legal/governance gaps, power imbalances and trust issues, highlighting the need for data sharing and the complexities of participating LMIC where such outbreaks often occur.

Interoperability and integration: bridging the gaps

Interoperability and integration are two further challenges requiring attention. Interoperability is contingent on the existence of standardized metadata, common data models and IT infrastructure, to allow for seamless exchange of data with successful examples available for imaging, genomic and clinical data (24). The interoperability challenge is impacting LMIC biobanks more, as those in high-income settings are better able to modernise existing IT infrastructure. In comparison, LMIC biobank IT systems are often legacy systems from different projects, with limited access to robust LIMS. The control over data formats -directly affecting interoperability- often resides with the proprietary software, which may be difficult to change or adapt for LMIC settings. Integration is a complex challenge in One Health and Global Health biobanking as it entails the integration of biobank data with other critical health data sources (e.g., Electronic Health Records (EHRs), environmental and animal health databases, etc.). Significant steps are the integration of complex '-omic' derived datasets, as a technical pre-requisite for One Health approaches (25). The next step towards One Health, is the integration of entire digital platforms, as opposed to unique collections (26). However, doing so infers the implementation of complex digital solutions for data management and control (27), and the closer integration of systems locally, so that they can be integrated at the global stage (28). The current LMIC biobank status is that of fragmented information systems, thus, limiting the participation in large-scale One Health and Global Health initiatives. Recent One Health examples have demonstrated the urgency of implementing sufficient technical infrastructure to overcome these challenges (29, 30).

Future grand challenges

We believe that one of the major challenges in biobanking for One Health and Global Health is addressing the lack of diversity in existing biobank collections. This holds true both for the human diversity, as well as for the environmental sampling, where high-income settings tend to be over-represented, and thus limiting the generalizability of research findings (31–34). Even with the ongoing efforts considered, there still needs to be a direct LMIC perspective more visible on efforts to achieve equity in biological and data sampling representation. Equally critical is the question of long-term sustainability, as biobanking requires stable and predictable resources to maintain infrastructure, quality standards, and trained personnel over time. Current funding models are fragmented, short-term, or project-based, which creates vulnerabilities in continuity and undermines the capacity of biobanks to serve as reliable research partners for One Health and Global Health. Addressing these challenges will require innovative and diversified funding approaches adapted to LMIC needs, that combine public and charitable investment, international cooperation, and local stakeholder engagement.

Furthermore, biobanks are predicted to play a critical role in the implementation of Artificial Intelligence (AI) in future research studies,

as they hold increasingly growing volumes of systematically recorded, and curated data (25). These data can be leveraged by researchers, in particular in the fields of One Health and Global Health, where the questions may require quite complex methodologies to be answered (35, 36), though, the implementation of AI in research based on biobanked data, is still in its early stages. LMICs could draw on existing ethical AI frameworks for responsible and equitable AI implementation, such as WHO's guidance on AI in health, which emphasizes transparency, inclusiveness, accountability, and data protection (37). While there is great promise, there are questions over the interpretation – for example, the algorithmic bias and explainability of the algorithms that are implemented (13). Moreover, the control over AI development is often concentrated in high-income countries that can carry the risks of: bias amplification (if the AI model is trained on non-representative data); lack of local capacity building within LMICs, and ethical oversight challenges (when the algorithm is designed and applied in two distinctly different contexts).

The power of networks

As part of the quest for improved quality in the biobanked samples, the creation of networks has been catalytical to the development of biobanking by enabling standardized practices, resource sharing, and collaborative research across institutions and borders (38). These networks foster trust, data harmonization, and scalability, which are essential for large-scale, high-impact biomedical and translational research (Figure 1). Indeed, addressing the complex, intersectoral challenges within One Health and Global Health requires a shift from isolated biobanks to interconnected, collaborative networks that allow at a minimum the sharing of best practices and protocols. Several biobanking networks in recent years have emerged with the aim of providing resilience, through standardization and capacity building, to the individual biobanks that are their members. These networks can be national, i.e., supported by the government or national associations (39, 40),; the result of a crisis such as the COVID-19 pandemic (41); or based on a shared linguistic background and -by extension- mutual cultural understanding (42). The Lusophone biobank network for tropical health (42), is an example of regional and LMIC-focused collaborative network that can be leveraged to address One Health research. Importantly, such networks have the potential to ensure capacity building, training and technology transfer both in physical and digital operations, thus accelerating the access to larger, more diverse datasets with greater local control over the AI deployment. It is through these networks that LMIC biobanks in One Health and Global Health are more likely to contribute, benefit and have agency in the digital research ecosystem. It is important to note that there are also fewer, yet successful examples of biobanks achieving interoperability without reliance to extensive networks, such as the Golestan cancer biobank in Iran (43), and the King Hussein Cancer Centre Biobank in Jordan (44).

Conclusion

Biobanking plays a foundational role in current research through the provision of high-quality, standardized, research-ready samples and data. It can do so at scale, thus supporting many of the '-omics' research initiatives globally. From this

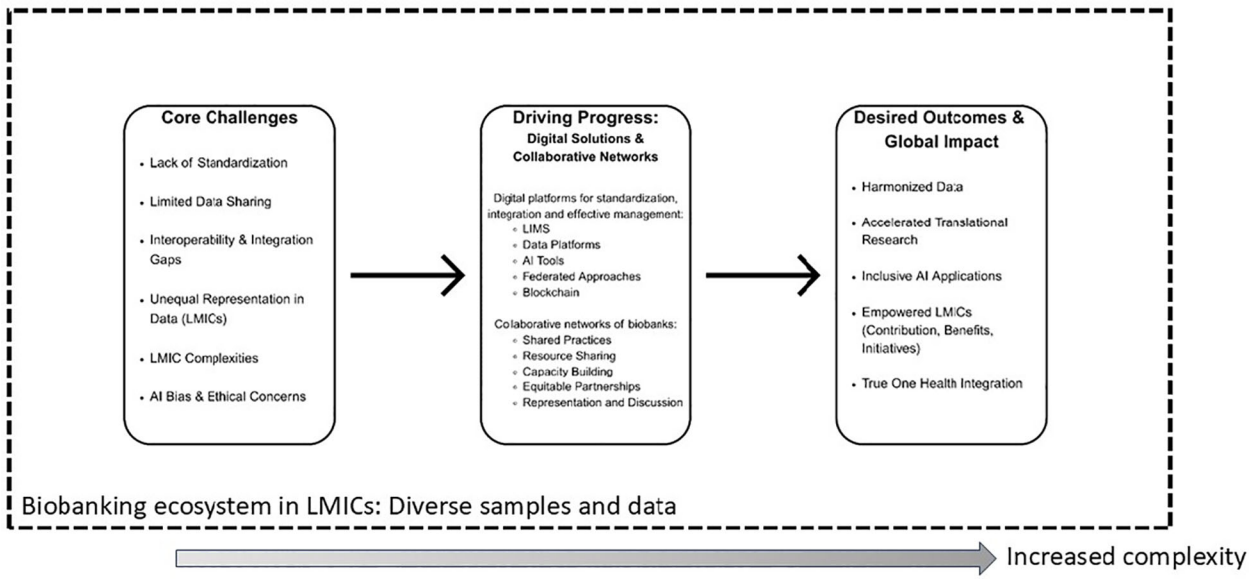

FIGURE 1
Biobanking's path towards effective One Health and Global Health equity. The figure illustrates how core intersectoral challenges in biobanking can be addressed by leveraging the power of strategic digital solutions and collaborative networks, leading to impactful and equitable global health outcomes within a One Health framework.

perspective, it is anticipated to play a critical role in addressing challenges within the One Health and Global Health frameworks. However, these challenges include the need for standardization of sample and data, the implementation of quality controls, and the ability for extensive data-sharing.

As One Health and Global Health questions are complex, they would lead to a need for greater interoperability and integration of existing biobanking capacities. While this is technically challenging, it is not impossible, as recent experiences and some early successes demonstrate. One of the main considerations remains the degree to which collections and biobanks in LMIC settings are able to contribute to such complex research, entailing the potential danger of bias for the interpretation and generalizability of results. Biobanks have the opportunity to respond to such challenges through the strategic development of and strengthening of collaborative, equitable, and intersectoral networks that leverage digital solutions to empower local stakeholders and ensure shared, rather than centralized, control. To achieve this, policymakers must create enabling governance frameworks and funding mechanisms that prioritize equity and inclusion, biobank managers must commit to adopting interoperable standards and ethical AI practices, and funders must support capacity-building initiatives that empower LMIC biobanks to be full partners in international networks.

Author contributions

QW: Writing – original draft, Investigation, Conceptualization. JL: Investigation, Visualization, Writing – original draft, Methodology. IC: Conceptualization, Investigation, Supervision, Writing – review & editing. ZK: Writing – review & editing, Conceptualization, Supervision.

Funding

The author(s) declare that no financial support was received for the research, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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