Review Article

Precision global health: a roadmap for augmented action

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Abstract: With increased complexity in various global health challenges comes a need for increased precision and the adoption of more tailored health interventions. Building on precision public health, we propose precision global health (PGH), an approach that leverages life sciences, social sciences, and data sciences, augmented with artificial intelligence (AI), in order to identify transnational problems and deliver targeted and impactful interventions through integrated and participatory approaches. With more than four billion Internet users across the globe and the accelerating power of AI, PGH taps on our current augmented capacity to collect, integrate, analyse and visualise large volumes of data, both non-specific and specific to health. With the support of governments and donors, and together with international and non-governmental organisations, universities and research institutions can generate innovative solutions to improve health and wellbeing of the most vulnerable populations around the world. In line with the Sustainable Development Goals, we propose here a road map for the development and implementation of PGH.

Keywords: Digital health; big data; artificial intelligence (AI); public health; machine learning; one health

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Defining precision global health (PGH)

The concept of precision entered the health sphere with the advent of digital and technological innovations, as it holds promise to better tailor care based on a person's genotype (1,2). Recently, precision public health (PPH) has triggered a vibrant debate. One side claims that placing emphasis on the individual and biological determinants of health risks neglecting the social and environmental dimensions of health (3,4). The other side argues that PPH simply uses the best available data to inform appropriate, setting-specific and timely public health interventions (5-7). Here, we appreciate both views and suggest the application of precision to broader transnational problems that are inherent to global health, particularly among marginalized populations (8-11). We theorise that using digital innovations will allow the generation, analysis and synthesis of existing and new data streams, from health and non-health sources, in near-real time to inform both public and global health interventions and improve the outcomes for populations. In the same fashion that public health provided the foundations for global health, PPH provides them for PGH in an increasingly globalised world (12,13). PGH leverages life sciences, social sciences, and data sciences, augmented with artificial intelligence (AI), in order to identify transnational problems and deliver targeted and impactful interventions through integrated and participatory approaches.

Several high-profile failures clearly demonstrated the limitations of not integrating knowledge and domain expertise pertaining to major global health issues. For example, the huge overestimation of flu cases in the 2012–2013 season in New York City by Google Flu Trends was partly attributed to a failure in the programme's algorithms to integrate the search behaviour of its users (14). The current Ebola epidemic in the Democratic Republic of Congo offers another interesting example. Although important lessons have been learnt since the 2014 epidemic in West Africa, projecting the spread of the 2018–2019 ongoing outbreak remains challenging because of the inability to integrate the complexity of the socio-political situation in this war zone. Indeed, medical progress to support patients and communities affected by Ebola is insufficient if social distrust is not adequately recognised and addressed (15).

PGH offers an opportunity to overcome these challenges with a big data-driven integrative approach (11,16) and the implication of the relevant stakeholders. With more than half the global population connected to the Internet, mainly through mobile phones, and areas such as Africa leading the annual growth of active mobile social users with over 17% in 2018, the role of local populations is more important than ever (17). Technology and social innovation can empower individuals within a population, making them active players in their own health and wellbeing, identifying challenges and working together to find solutions (18,19). In this paper, we advocate for PGH, a transformative approach that offers opportunities beyond the health sector, and we discuss its development and implementation, as well as the challenges around impact evaluation, ethics, and policy. We propose a strategic road map for action focusing on three priority areas.

Advancing PGH

Undoubtedly, major public and global health achievements have resulted, at least in their initial stages, from generic interventions. The eradication of smallpox with large-scale vaccination campaigns is a key example of such an intervention (20). The iodization of salt for the prevention and control of iodine deficiency disorders, and improved access to clean water and oral rehydration salts for prevention and control of diarrhoea, provide additional evidence of the success of large-scale generic public health interventions. However, "one size fits all" interventions tend to neglect the complexity of changing social-ecological systems, heterogeneity of populations and their health determinants (21). In the fight against HIV-AIDS in the early 2000s, for example, the strategy was about scaling up already successful interventions, but often without the necessary evaluation of the factors that might impede these interventions. The discussion was about how large disease-specific initiatives impacted health systems (22,23). Similarly, global policies for both vaccination and tobacco control have been impactful, but even in countries where they are largely applied, one faces either increasing vaccine hesitancy or refusal, with growing pockets of unvaccinated sub-populations (24), or plateauing in the declining prevalence of tobacco smoking, with an apparent impossibility to reach elimination (25). It is now widely accepted that often generic approaches are not generalizable across disease and health systems, and the prevention, control and elimination of diseases may ultimately depend on the combination of generic and targeted actions (26,27). Overall, we can hypothesise that with increased complexity in various global health challenges comes a need for increased precision and the adoption of more tailored strategies.

One of the most fundamental challenges for the implementation of PGH is that a large part of the global population, especially in low- and middle-income countries (LMICs), remains invisible due to the unreliability or absence of basic electronic information systems including, for example, vital registration data (28). This naturally leads to poor data availability and quality, as well as preventing health system integration and regulation, which ultimately limits the implementation of big data or AI driven interventions (11).

Implementation of PGH at the systems level

High-income countries (HICs) such as Australia, Canada, and the UK, among others, are increasingly opening national data from multiple sectors, including demographics, education and health (e.g., Open Data Barometer) (29). In addition, some health systems are now highly digitized and interconnected, for example in Estonia. In India, the Aadhaar Programme, the world's largest biometric identification system has registered 1 billion of India's 1.3 billion inhabitants (30). Meanwhile the INDEPTH network with a host of demographic and health surveillance systems (DHSS) in Africa, Asia and elsewhere, assembles large-scale population data with great potential value for public and global health. The Global Burden of Disease (GBD) Study and the work by the Institute of Health Metrics and Evaluation (IHME) on integrating, analysing, and visualising at a high resolution (e.g., precision maps) morbidity and mortality data on infectious and non-communicable diseases from countries across the world, provides foundations for the development of PPH and PGH (7). Similarly, the Infectious Diseases Data Observatory (IDDO) offers an innovative platform to support more precise research-driven responses in the context of emerging and neglected infections. PGH can transform the approach to reduce the burden of infectious diseases affecting LMICs to the same extent it has been achieved in HICs (6,13).

The following case examples demonstrate some specific applications of PGH to Rift Valley fever (RVF), tuberculosis (TB), non-communicable diseases, and accessibility to healthcare.

Using remotely sensed environmental data and community surveillance for risk profiling and control of RVF

RVF is a zoonotic arbovirus transmitted to humans through contact with blood or tissue of infected livestock directly or indirectly through mosquitos (31). These mosquitos, and thus the spread of RVF, are influenced by rainfall and flooding in the Horn of Africa, which have increased in frequency and severity due to climate and weather anomalies (32). The virus was first identified in 1931 in Kenya and since then major epidemics have been reported in different parts of Africa and in the Middle East, affecting both livestock and humans (33). Kenya, for example, experienced major outbreaks in 1997/98 and 2006/07 with 450 and 158 human deaths, respectively, with major associated economic losses (i.e., the 2007 outbreak had an estimated cost for Kenyan economy of over US$ 32 million) (34-36). In 1997/1998, despite available control measures including an effective licensed vaccine for cattle, the detection of and the response to the outbreak were slow, mainly due to late warning signals, poorly-developed community surveillance, delayed aetiological diagnosis, and a lack of communication between veterinary and public health sectors (37). On the contrary, in 2006/2007 the response was facilitated by the early predictions of risk of RVF due to heavy rainfall based on remotely sensed environmental data (32). Integration of anticipatory monitoring data for disease risk, in this case using a global information source collected from other sectors, can help to make better sense of different signals (e.g., expected rainfall, seasonality factors, vector and host range, and production system changes) and to target resource in real-time. Demographic, ecological, environmental, and socio-economic predictors (e.g., vegetation cover, precipitation, soil type and socio-economic status) can help to identify RVF hotspots and target surveillance at the right time and location (38). With RVF joining WHO's Blueprint list (39), Kenya has been moving towards an integrated surveillance and response system, based on cross-sectoral collaboration and community participation (e.g., cattle herders) through digital tools. The Kenyan governmental Zoonotic Disease Unit has favoured data sharing across sectors and joint prioritization for targeted control of zoonoses (40-42). In collaboration with mHealth Kenya (43), mobile phone technologies have been integrated in surveillance systems, improving the country's capacity to detect and control zoonotic diseases, such as RVF, more quickly and precisely (44,45). However, to achieve precision in the detection, prevention, and control of RVF, the country needs data intelligence: the capacity for near real-time analysis to understand data signals from multiple interoperable sources. Such data intelligence should be converted into usable tools such as the RVF risk-based decision-support tool intended to guide directors of health and veterinary services and partners on the decisions to prevent and control the impacts of RVF epizootic (46). The Kenyan approach is promising and could be extended and further developed regionally to aim for the elimination of RVF in the Horn of Africa.

When precision becomes a global health instrument to improve TB care and control

Promoted by WHO between 1995 and 2006, the Directly Observed Treatment, Short Course (DOTS) strategy was implemented globally. It is an essential package covering TB care and control regardless of the socio-cultural and health systems settings (47,48). However, emerging drug resistance and co-morbidities have challenged this strategy, urging for a much more effective approach (49,50). Although not yet point-of-care tests, the introduction of rapid molecular diagnostic tools is of considerable benefit to TB detection and treatment, as well as surveillance and other programmatic needs (51-53). The increasing availability of genome sequencing technologies, including next-generation sequencing, allow for more rapid and precise detection of anti-TB drug resistance mutations for all first- and most of second-line drugs (54). One technological advance [Deeplex MycTB (Genoscreen©)], has already been successfully used in South Africa and Djibouti for surveillance purposes (55,56) and another kit with similar characteristics has been developed in the US (57,58). Once this technology is also proven effective on clinical grounds, one could design strain-specific regimens. The resistance pattern of the strain can then be combined, through an AI-operated clinical decision support system, with the patient's data on co-morbidities, on concomitant use of medicines, resulting in pharmacovigilance, precise regimen prescription and care management (59). This should be first established at a well-resourced central level, connected to both the clinical care sites and the national programme as well as at global monitoring institutions, facilitated by rapid, easy-to-operate and inexpensive technologies. Beyond patient care, this system could in fact support programmatic functions, such as surveillance of TB and drug resistance, or pharmacovigilance nationally and internationally through apps for care providers and patients. In concert with global standards like GS1 (The Global Language of Business) and supportive technologies like blockchain, the system may also facilitate less expensive, more reliable drug procurement and supply operations at scale. Ultimately, the system will need continuous feedback information for adjustment and refining of diagnostic and treatment options with global validity. This model, which relies on coordination of innovative but existing technologies and their integrated utilization, needs to be assessed under operational conditions in high-burden countries to test feasibility, acceptability, affordability, scalability, impact, and long-term sustainability. Human factors such as social support and counselling, and the degree of standardization for at-scale operations, are also critical. Overall, this is an excellent opportunity to merge precision in individual care and precision in key public and global health functions such as disease monitoring and evaluation, drug procurement, and pharmacovigilance. Maintenance of a certain level of programmatic standardisation to facilitate expansion of precise care delivery is a fundamental aim that is not mutually exclusive with a more precise care approach and needs to be assessed in different settings worldwide.

Opportunities and challenges for PGH for diabetes and other non-communicable diseases

In 2017, there were an estimated 425 million individuals living with diabetes globally, with this expected to increase to 630 million by 2045 if current trends continue (60). In 2012 the WHO and International Telecommunication Union (ITU) launched Be He@lthy, Be Mobile, an international initiative working with governments to scale up mHealth and access to health services to improve prevention, management, and control of non-communicable diseases and their risk factors.

In this context, the opportunities for PGH vary in their scope, from devices that gather patient data for self-management or for guiding clinical decisions, to broader approaches integrating data on upstream determinants of health behaviours and living environment, including tobacco consumption, physical activity, and diets. For example, the Food Monitoring Group has created a global, branded food composition database that serves as an ongoing, independent, and systematic monitoring and reporting system for packaged foods. Such systems will be imperative for monitoring success (or failure) of implementation of major dietary policies set by WHO, including the goal to eliminate artificial trans fats by 2023 and reduce dietary sodium consumption by 30% by 2025 (61-63). The transformation of food production, manufacturing, sales, and consumption recommended by the 2019 Lancet/EAT commission on healthy diets from sustainable food systems (64) requires action and large-scale, yet granular, surveillance at every level to avoid exceeding predefined limits for climate change, biodiversity loss, freshwater use, disruptions to the global nitrogen and phosphorus cycles, and land-system change. Pedometers, affordable smart watches, an increasing number of sensors on phones, new means of measuring blood sugar, cuff-less blood pressure devices, point of care diagnostics, and low-cost ways of capturing data from digital devices in the field, among other examples, generate increasing volumes of data on individual health and behaviour (65-67) With non-communicable diseases as the leading cause of death globally, the opportunities in PGH must be leveraged and developed in equitable ways to improve health and wellbeing in both HICs and LMICs.

Modelling geographic accessibility to healthcare and optimizing supply chains through drones

Measuring geographic accessibility to healthcare has traditionally used distance-to-model population catchments around health services. Time-based catchments integrating constraints of the landscape (e.g., topography), infrastructure (e.g., road network), and modes of transport (e.g., motorized or walking) are more realistic, contemporary, and precise approaches to planning for health systems in resource-limited settings. In sub-Saharan Africa, 30% of the population is over 2 hours away from the nearest emergency care facility (68), which motivates for an improved distribution of services. With increasing availability of high-resolution geospatial and environmental datasets, participatory cartography (e.g., OpenStreetMap), and the motivation for improving national health information systems (e.g., Health Data Collaborative) (69), accessibility modelling can be ameliorated. Further improvements include integrating the geolocation of health facility attendees' home (70) and automatic derivation of their modes of transport (71). Where a lack of physical accessibility hampers effectiveness of supply chains, essential health products or tools might be delivered using drones (72,73). The government of Rwanda has used drones since 2016, through the drone company Zipline, to deliver blood to 21 district hospitals in the country at relatively low cost, reducing the average blood delivery time from several hours to less than 45 minutes. As of April 2019, the service has delivered more than 13,000 units of blood, contributing to avoid numerous preventable deaths (74). In April 2019, Zipline launched the world's most extensive drone delivery network in Ghana, with a revamped fleet of larger and faster drones able to deliver blood transfusion supplies, vaccines, HIV medications, antimalarials, antibiotics, lab reagents, and basic surgical supplies. Drones are being tested for a number of other health applications including support for

TB control (75), and delivery of snakebite antivenoms (76) or contraceptives (77). Although clearly in its infancy, and curbed by currently restrictive national air regulations, the field of deploying drones for medical delivery has passed the proof-of-concept phase in many places and appears ready for targeted scale-up in the PGH agenda.

Evaluating the impact of PGH

A key novelty and impact of more precise global health service and benefit delivery through PGH, is its potential to enhance effective resource allocation (4), a crucial step to achieving SDG10 of the Sustainable Development Goals (78). Improved targeting of interventions to those who need them most, and when and where they need them, maximizes impact. This would also allow us to uniquely identify the specific population of interest and the relevant barriers, comorbidities, and other factors that may affect expected outcomes, so that we can more precisely design cost-effective and efficient solutions, and those that might incur cost-savings, and evaluate impact (79). The impact of PGH can be measured at different levels using existing monitoring and evaluation tools but enhances our abilities to yield the following benefits. First, PGH might foster immediate and long-term health benefits through improved prevention, monitoring, detection, and treatment of disease, and provide essential population health status indicators such as disease incidence and prevalence, case fatality and recurrence rates, and their contribution to burden of disease (80) through better evidence-informed disease control priority setting. Second, PGH can help bridge gaps and reduce inequities in existing strategies through support to targeted identification of the needs of populations. At the same time, integrating information from relevant sectors may increase statistical power, allowing for more precise forecasting, such as in the detection of RVF risk through joint human and animal data collection that may be missed through separate, uncoordinated systems (81). Indicators of effectiveness or efficiency, such as reduced time for life-saving treatment delivery or the more rapid investigation, diagnosis, and trace-back to the exposure source, might also help to interpret how well a system is functioning to inform disease prevention and control actions (82). Third, PGH might even generate financial savings. While precision preventive health interventions incur upfront costs, these should be balanced against the potential long-term savings that they may yield for individuals, investors, and society, through preventable later-stage disease management and economies of scale. Screening for non-communicable diseases and the application of mass customization principles are two examples where cost savings would result from effective early intervention (83,84). Fourth, PGH might also drive large geographic scale and multi-sectoral benefits for society and the environment by identifying and targeting resources where they can deliver greatest value. The need to assess options, both in terms of trade-offs and gains, supports the need for a community-based, participatory and multi-sectoral approach that can be achieved by capturing wider societal outcomes linked to health interventions and improvements when considering cost-effectiveness (82-85). In addition to health sector-relevant outcomes, evaluation should be meaningful to other stakeholders to incentivise their contributions to disease risk reduction activities. Fifth, PGH will enhance the dissemination of lessons learned and of best practices. The digital innovations that PGH embraces should not overshadow the importance of other outputs, such as knowledge sharing, capacity building and development of coordination mechanisms, which remain important for ensuring that policies and interventions are effective and are disseminated in order to contribute to the broader global good through lessons learned (in fact, digital pathways may help make these more accessible). Impact should also be measured by established frameworks for evaluating intervention effectiveness; these include approaches like the Reach, Effectiveness, Adoption, Implementation, and Maintenance (RE-AIM) framework (86,87) and the Consolidated Framework for Implementation of Research (88).

Ethics and policy of PGH: unresolved issues and emerging opportunities

PGH is intimately connected to the data life cycle. As such, questions about the origin of these data, conditions of their use, the type of analyses performed on them, and the purpose of analyses are of critical ethical and legal relevance (11). A fundamental challenge for data-related projects is to ensure that data utilisation does not inadvertently harm individuals or groups. Violation of privacy, for example, can severely affect well-being if it results in discrimination, stigmatisation and social exclusion, particularly in regions where legal protection from such privacy related harms are less robust. Global health has traditionally been afforded legal exemptions that allow the public interest to override individual liberties including privacy rights. While emergencies can activate such ethical and legal allowances, these are not generally extended to all aspects of global health work nor are they automatically extended to all types of data sets that PGH might access. Protection of privacy is often seen as an obstacle to data access; however, perceiving privacy and data utilisation as a zero-sum game is flawed (89,90). Data access and sharing in global health have been recurring challenges attributed not only to privacy concerns, but also to unaligned incentives, ambiguous data ownership, and attribution of credit. Adhering to principles of research partnership, innovative data governance models, and oversight mechanisms that promote accountability can help overcome such challenges and can prevent the exploitation of privacy or data ownership claims that obstruct legitimate and ethically justified data access for global health purposes. Such governance models are rooted in partnership principles and data fairness, with the latter prescribing the utilisation of data for the promotion of public good (91).

As PGH includes non-traditional health data sources (92), potentially relevant data (e.g., from social media sources) are often under the control of powerful non-state actors who also possess analytical capabilities that can surpass those of the state. Exclusive access to these data sources and development of proprietary algorithms for their analysis poses several challenging questions. We refer specifically to the responsibilities and obligations of these non-state actors in contributing to the PGH approach. The 2014/2015 Ebola crisis in West Africa highlighted some of these concerns when access to private telecommunication data was sought to support control of the outbreak. The time lag between request and access to data reflected the lack of clarity about the role of private data controllers, their obligations to global health, as well as their liability risks (93). As argued in the United Nations Guiding Principles on Business and Human Rights, non-state actors such as corporations, have responsibilities towards global justice and human rights independent of their legal duties (94). Hence, some non-state actors may bear specific responsibilities to contribute to global health activities (e.g., corporations collecting data that can be used for monitoring in a country that is lacking a state monitoring system) while simultaneously having a duty to respect individual rights. A specific framework of how this can be achieved in the health domain is missing; yet, it is urgently needed.

The speed of digital transformation across the globe may lead to the assumption that data relevant to global health are also generated by all those in need of better health services. This assumption is reinforced by a closing digital divide, demonstrated by the increase in Internet penetration. However, Internet penetration is a limited informative metric alone. If the digital divide is understood as mental access (i.e., fear of or disinterest in technology), material access (i.e., no ownership of hard- or software, or lack of network coverage), skills access (i.e. lack of knowledge or education on how to use technologies), and usage access (i.e., lack of useful applications) (95-97), disadvantaged populations are more likely to be excluded and be least represented in population health datasets (98). Other important factors include gender, age, education, consumer behaviour, cultural norms around who accesses digital tools, and health seeking patterns (99-102). This lack of diversity is well-documented in most health research data with genomic-based data being a more recent and well-described example. Currently, the greatest proportion of genomic data comes from individuals of Caucasian and Chinese origin with Africans being grossly underrepresented (102). This lack of diversity in data sources can distort findings, increase biases in machine learning-based algorithms, maintain or worsen inequities, and curtail the contributions PGH could make.

For PGH to develop as an impactful approach, ethical considerations related to fair data processing and benefit sharing are paramount (103). Many big data processing activities related to global health have focused on outbreak detection and disease monitoring as components of health security more broadly, which prioritises public health emergencies. Despite the immediacy and magnitude of the threat these emergencies pose, they should not monopolise the focus of PGH. If the benefit of PGH is to be equitably distributed, then it should encompass broader aspects of global health and regional needs based on disease burden and local priorities. This locally-driven prioritization is an ethical imperative for PHG and represents an opportunity to reduce health disparities. Moving forward, PGH must be integrated into existing ethical frameworks as must embrace emerging ones in the digital health era. The latter have a stronger focus on data processing needs and can therefore address some of the most fundamental ethical issues in PGH. For example, a recent proposal includes the systemic oversight approach, which responds to the features of the evolving health data ecosystem including its temporal dimension, the multiplicity of data uses, the limitation of informed consent, and the presence of diverse stakeholders with misaligned aims (104). Such approaches have a better chance of creating reliable conditions for the development of PGH and the sustainability of public trust in PGH-based approaches for health promotion and disease surveillance, prevention, and control activities (105).

Road map to PGH

Our group firmly believes that leveraging digital tools to have more precision in global health can lead to improved health and wellbeing (106). In order to stimulate progress we propose a road map for action focusing on three main priority areas:

Develop awareness, build capacity, and create a commitment to PGH

- Promote and develop PGH in educational and research programmes that integrate data sciences, life sciences, and social sciences to advance the PGH workforce;
- Advocate for PGH in national and international political fora, involving international organisations, particularly the WHO, to develop awareness and to create political and financial commitment for implementation by member states;
- Build capacity in the use of digital devices (e.g., tablets and smartphone) and associated software (e.g., apps, diagnostic management algorithms) across the health system, particularly among health professionals working in the field, and across communities using citizen science and other participatory approaches.

Identify and agree on needs and opportunities for implementation of PGH

- Identify opportunities and challenges of the global health agenda, grounded in the Sustainable Development Goals (taking into account issues related to planetary health), where PGH can facilitate the achievement of specific targets (e.g., elimination of disease; access to health care facility and medical and preventive services) to improve health and wellbeing for all;
- Engage and empower populations for their active participation in problem identification and solving through citizen science and digital tools.

Establish a learning global health system for the practice and evaluation of PGH: mechanisms, tools and resources

- Engage key stakeholders to foster the development and implementation of innovative tools and mechanisms for the practice of PGH;
- Develop participatory approaches (e.g., citizen science) and open data policies when collecting, sharing, and utilising all relevant data, produced for both health and non-health purposes;
- Develop an evaluation framework and assess the impact of PGH interventions;
- Integrate life sciences with data sciences and social sciences by developing mathematical models, and subject them to a continuous learning process based on experiences;
- Develop, evaluate and maintain real-time nowcasting and forecasting platforms for emerging health issues and implement policies and preparedness plans to support and guide early warning systems and precision response;
- Establish legal and ethical frameworks that facilitate the implementation and development of PGH in countries with different levels of digitalization of health systems;
- Ensure funds for education, research and implementation of PGH using existing initiatives and through innovative mechanisms such as the creation of a global fund for PGH.

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Footnote

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