

THE NEXT ERA IN

GLOBAL HEALTH

by COPENHAGEN INSTITUTE FOR FUTURES STUDIES

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GLOBAL HEALTH

How to enable quality of life and wellbeing? THE NEXT ERA IN

GLOBAL HEALTH

Authored by The Copenhagen Institute for Futures Studies Funded by Novo Nordisk Business Innovation Garage

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What will health look like in the future? When we think about the future, we tend to think that it will be "more of the same," which in terms of future health means more medical technology, new and improved drugs and treatments, better health, and longer lives, continuing the steady century-long trend of life expectancy increasing two to three months every year. While all of the above will likely be true, several challenges lie ahead that will complicate the picture, as well as a range of opportunities that hold the potential to revolutionize health to not just be "more of the same," but something radically different from today. In fact, if we are collectively to handle the challenges ahead, we need to radically change how we think of health and how we deal with health.

Technology will play a major part in this shift. Digital technology will remain important with advances in artificial intelligence, sensors, robotics, and smart prosthetics; but in addition to this, genetic technology and other bio-technology will play a much greater role than today, with cheaper genome sequencing, better knowledge of the role of genes in health and genetic treatments such as gene therapy, and replacement organs grown from stem cells. Advanced personal technology will also enable a democratization of health services, where tests and procedures that now are very expensive and require skilled professionals in the future will be put into the hands of ordinary citizens.

Three key phrases of this shift will be preventive healthcare, data sharing, and personal health. We can improve health and save resources simultaneously if we can prevent people from getting sick or act before a disease becomes serious. Personal monitoring technologies such as smart wearables can keep citizens and their doctors up to date about their health status and provide early warnings for impending health problems. All sorts of personal health data – genetic data, behavioural data, and even location data (as used by tracking apps during the COVID-19 crisis) can be collected and analysed by artificial intelligence to provide real-time actionable information about both personal and public health.

In this report we look at these issues and other challenges that must be overcome to revolutionize health. We also look at some of the technologies that will help improve health in hitherto unseen ways, possibly even ushering in an age where health can be preserved and improved beyond existing natural boundaries.

About the Business Innovation Garage: The Business Innovation Garage is a newly formed department within Global IT that identifies and drives growth opportunities created by emerging technology. Our strategic focus is on solutions and technologies that are new to Novo Nordisk and new to the pharma industry.

Interested in understanding how the trends and scenarios in this report could impact your area? Do you have an idea for a game-changing approach to our business?

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THE NEW REALITY OF HEALTH

With the proliferation of new health technologies, we will soon bear witness to a revolution of the world's healthcare systems. The idea of what constitutes a healthy person is changing with a better understanding of granular biological processes as well as a more nuanced understanding of what determines an individual's health. Healthcare systems should focus more on prevention than only treatment and move away from the industrial mindset where everyone is treated the same way to acknowledging that individuals are different. A central element in the coming healthcare revolution will be extensive collection, sharing, and analysis of health relevant data, making it possible to intervene sooner against both epidemics and individual diseases. This new paradigm is defined mainly by three key trends: demographic developments, the growing burden of non-communicable diseases, and the expanding role of technology.

CHALLENGES IN GLOBAL HEALTH

Health systems of the future will be put under significant pressure because of several demographic developments. Advanced economies are struggling with ageing populations with longer lifespans, which may present issues like increased susceptibility to non-communicable diseases, a shrinking work-force, and increasing long-term care costs.

According to Andrew Scott, Professor of Economics at London Business School, a distinction between ageing and longevity needs to be made. He argues that there are two competing effects, the 'ageing effect' and the 'longevity effect'. The ageing effect is that older cohorts of the population are growing, which leads to a rise in average overall mortality rate because mortality rates are higher among the elderly. This ageing effect is offset by the longevity effect, which mainly derives from better medical technologies and health factors like lower rates of smoking. The longevity effect essentially means that older people are biologically 'younger' than before. This is underlined by data from the US, where average age increased from around 31 in 1950 to around 38 in 2015, while average mortality rates declined from about 9.2% to about 8.2%. Similar trends are seen across most developed economies, showing that the longevity effect has more than offset the ageing effect when it comes to mortality.¹

Emerging economies are at the stage of development where they can reap the benefits of a young and productive population. They are also deeply affected by the ageing and longevity effects, although to differing degrees. Scott argues that countries that have experienced rapid growth also have gone through the demographic transition very quickly, which could lead to a stronger ageing effect that must be offset by increased longevity. While these regions and countries are experiencing high birth rates, it is of utmost importance that they take advantage of the so-called 'demographic dividend', which is the opportunity provided by young populations to increase productivity through better usage of technologies and good policymaking to offset the inevitable ageing effect. The advanced economies have already begun focusing on quality of life (QoL) and wellbeing rather than just longevity - after all, productivity correlates with quality of life. Emerging economies will inevitably need to face the challenge of providing the best QoL while also capitalising on the demographic dividend.

Another underlying issue within ageing is the increasing mortality rates as people grow older, which are mainly due to noncommunicable diseases (NCDs). Most of

the world has already made the epidemiological transition from communicable diseases being the main cause of death to NCDs making up the majority (sometimes in combination with prevalent communicable diseases like malaria). According to the Institute for Health Metrics and Evaluation, 62% of global disability-adjusted life years lost (DALYs) in 2017 were due to NCDs, while in 2000 it was only 47%.² In 2016, 86% of DALYs from communicable diseases (CDs) were from low-income and lower-middle-income economies. This shows that not every part of the world has gone through the epidemiological transition; in fact, these regions suffer from a dual burden of disease from both NCDs and CDs.

Technology has been hailed as the saviour of healthcare for the past decades because of the benefits it offers, such as improved longevity in most of the world. However, technology can be seen as a double-edged sword since technological innovation is notorious for being extremely expensive when first implemented – though there are notable examples of technological innovation making healthcare far less expensive, such as mobile health and wearable medical devices.

Another seldom-discussed aspect is the lack of focus on mental health. According to the World Economic Forum's 2019 Global Risks Report, mental health problems affect an estimated 700 million people, with a common theme being psychological stress related to a feeling of lack of control in the face of uncertainty.

It is projected towards 2030 that NCDs will cost more than USD 30 trillion, which was equivalent to 48% of global GDP in 2010 when the projection was made. This development may lead to swaths of people being pushed below the poverty line. Mental health conditions alone will account for

DETERMINANTS OF HEALTH



the loss of approximately USD 16.1 trillion over the same time span, which has an extraordinary impact on both productivity and quality of life for those affected and therefore must be taken into account.³

INVESTING IN THE FUTURE

While it is crucial for the future of digital health to have some form of infrastructure in place, decision makers cannot overlook that health is not just determined by medical care and health policies. The determinants of health, introduced in the 1970s by the WHO, visualized on the previous page has been further developed by scholars globally. It shows to what degree the health of individuals is affected by their physical environment, the medical care they might receive, genetics and biology, social circum stances, and individual behaviour.⁴ They are no less relevant today, especially when determining where investments should be made in the future health systems.

The WHO urges decision makers to consider all the determinants of health and see health as something much broader than just health policy. Social, economic, digital, and infrastructural policies all affect health to varying degrees, and hence reforms should be considered investments in health rather than just infrastructural cost. Today, most investment are going into medical care, i.e., the treatment of diseases in hospital settings, long-term care, and pharmaceuticals. Medical care only makes up approximately 11% of the determinants of health, while individual behaviour and social circumstances make up 60%. This is where investment is lacking, even though social circumstances like income and education as well as individual behaviour such as dietary habits and psychological aspects have a demonstrably large impact on health outcomes. It should not be so difficult to agree that more investment in these areas should yield much greater health outcomes than investing heavily in medical care. Therefore, the question is not whether we should do it, but rather how. It is an objective worth undertaking, even if the returns on investment are difficult to quantify.

SHARED RESPONSIBILITY FOR FUTURE HEALTH

Health has become everybody's business. Political, corporate, administrative, and societal responsibility all play vital roles in shaping the future of health.

The political responsibility lies in creating legislation and regulation that is dynamic and capable of adapting to future healthcare needs. This inevitably involves ethical discussions surrounding access to and use of personal health data, where we may see a radical change from researchers asking for and getting blanket consent to a dynamic consent setup where ethical issues are diminished.

Healthcare systems are incredibly complex, and significant reform cannot be implemented in the brief time politicians often desire. However, one thing is certain: In order to deliver on the United Nations' Sustainable Development Goal to "Ensure healthy lives and promote well-being for all at all ages", something must be done to secure better lifelong quality of life for all. Agreements must be made for long-term solutions that go beyond election cycles.

Future corporate responsibility will mainly be related to healthcare providers stepping up and becoming partners in health ecosystems rather than acting as siloed competitors. This includes setting up ecosystems of collaboration and engagement in public-private partnerships, as we are increasingly seeing today. It is difficult for e.g. pharmaceutical companies to be viewed as forces for good, as they are generally associated with making profit from disease. However, even today there is a shift in perception within some companies, as they are using their accumulated capital and influence to initiate ecosystems of collaboration among themselves and with the public system. Many such companies are making the transition to become 'data companies', with an increased focus on health data, as data are increasingly seen as the currency of the future.⁵ If prevention is the dominant paradigm in the future, their business models must adapt accordingly, with less focus on treatment, e.g. by helping individuals improve their health, with expert insights gained from both clinical and citizen-generated data.

Administrative responsibility is related to the reduction of bureaucracy surrounding innovation and the implementation of novel solutions. Cross-sector progress must be enabled by procedures that reward risk-taking in terms of advancing innovation and allow for adaptive behaviour. Dynamic regulation needs to be implemented, allowing administrators to shift from preserving the status quo to become promoters of progress.

Making the shift towards prevention cannot occur without society's support and not least - individuals taking more responsibility. Today, when individuals get sick, they often expect the health system to take care of them, depending on their local context. In the future, the responsibility for treatment will remain with the health systems, but individuals must take more preventive responsibility for their health and wellbeing. As an extension of the individual, health in the future will revolve more around the community and local settings, moving away from centralised superhospitals to decentralised community health centres.









PHOTO ZYDEAOSIKA

2020 was the year that an invisible enemy changed the world. In addition to the lives lost to the disease, it has had devastating effects on economies, societies, and healthcare sectors. In fact, most sectors were affected as the world started to close down, country by country, in the spring of 2020. While there is no doubt that COVID-19 had a negative impact in many aspects, it also has an interesting positive impact. The pandemic has spurred innovation and collaboration across borders and between competing businesses. In the wake of the pandemic arose new initiatives and inventions and also the implementation of digital solutions such as mHealth and telemedicine.

As COVID-19 started sweeping across the globe in early 2020, our healthcare systems were not equipped to deal with this crisis; an unpredictable, large-scale health challenge that required urgent mobilisation of resources and affected the entire population. Healthcare systems had to respond and adapt at an unprecedented pace, and the pandemic highlighted the shortcomings of healthcare systems in most countries. As the whole world reimagines public health and rebuilds its economy, there is a unique opportunity not merely to restore the healthcare system of the past, but to dramatically advance health and prosperity.

To control and contain the coronavirus as much as possible, safety measures were predominantly preventive. The public, in some countries more than others, showed that massive behavioural change was possible when forced by a widespread pandemic. Meetings and work went online; hygiene, social distancing, and handwashing became high priority; and people stayed home if they could – though unfortunately, these things weren't always possible for the world's poorest people. Out of necessity, we had to embrace many digital solutions for which we did not have the proper regulatory framework. It is imperative that such a framework will be built and that it will be interoperable across sectors and borders, enabling us to stand together and act promptly and in concert in case of a new pandemic or other catastrophes.

DATA PRIVACY SHOULD DRIVE DIGITAL SOLUTIONS

When we build a new framework, we must consider the opportunity for data-sharing across borders in a safe, transparent, and secure way. The earlier a disease outbreak is identified, the better our chances are to respond to it proportionately. Warning systems combining tracing and AI can be used to forecast, control, and possibly predict future outbreaks. The Canadian-built AI system Bluedot warned about signs of a flu-like virus spreading from China back in December 2019 – nine days ahead of the World Health Organisation's statement alerting people of an outbreak of an infectious disease. Forecasting systems combining epidemiological data, Twitter data, and other unstructured data to forecast disease outbreaks are under development.⁶

Sharing healthcare data across borders is a controversial and highly debated subject, even though the idea of globally collecting and sharing health data is by no means new, dating back to the late nineteenth century. There are incredibly good reasons for governments to protect their citizens' healthcare data, but there are also – with proper privacy and data security – plenty of reasons to share data a lot more than we do today.⁷ Standards, legislation, regulation, and proper oversight must be in place to protect privacy while also enabling global sharing and collaboration.

In order to mitigate spread of the coronavirus, contact tracing has become an important tool for many governments. Many contact-tracing apps have been offered, some voluntary and other less so, by governments. Unfortunately, some governments were too quick to develop apps, leading to severe compromise of citizen privacy and data protection. Countries such as Bahrain, Kuwait, and Norway have been strongly criticised by Amnesty International for using surveillances tools that go far beyond what is justified or even legal. According to Amnesty, for contact tracing apps to be human rights compliant, they must have privacy and data protection built in by design. The data collected must be the minimum amount necessary and securely stored, and they should be restricted to controlling the spread of COVID-19 and not used for any other purpose – including law enforcement, national security, immigration control, or commercial use.⁸

When tech giants Apple and Google joined forces to develop APIs that enabled interoperability between iOS and Android, they offered a decentralised and voluntary approach to contract tracing.⁹ Germany, a country that has not been on the forefront of adoption of new technologies, managed to develop an app that did compromise the privacy of the users. The German population take data privacy and protection very seriously, and hence the app was developed with maximum transparency. The design of the app is based on the least information possible, with no tracing of the data. Rather than GPS, which reveals location data, it is based on Bluetooth signals. The transparency and security delivered by the system led to a wide uptake by the citizens.¹⁰

Brazil was fast to realise the benefits of public-private partnerships, knowing that the Brazilian government cannot move as quickly as the business community. This led to 40 companies and 15 universities collaborating, led by Experian DataLabs, to build Brazil's 'COVID radar', a system that integrates companies with hospitals and communities that need donations of ventilators, personal protection equipment, and other supplies. It also provides case monitoring and disease forecast through self-diagnosis.¹¹

THE RISE OF TELEMEDICINE

To protect healthcare workers and limit the spread of the virus, the use of telemedicine has exploded during the pandemic. This could lead to a permanent expansion in the use of telemedicine and telehealth in general. For many people telemedicine is a new concept but it was first mentioned in 1879 in an article in the Lancet. The adoption to telemedicine has been slow, as it requires planning and resources as well as having regulatory, policy, and strategic frameworks in place. The level of implementation and readiness varies, with some countries such as France, UK, and Portugal already having established it before the pandemic, while others are in the developing or initial stages where they have laid the groundwork and are building the infrastructure for it. The COVID-19 crisis might become the catalyst for the widespread uptake of telemedicine. As few countries had the regulatory framework in place before the crisis, but many others had to bend the rules by temporarily relaxing the policies that have limited the

uptake of telemedicine. This might push decision makers and health systems to embrace telehealth as the future of health and medicine and start building the infrastructure and regulatory framework necessary for enable proper trustworthy implementation.

INNOVATION IN OTHER AREAS

As we grapple with the tragic COVID-19 pandemic, it is enlightening to see collaboration in multidisciplinary fields, sometimes between otherwise competing companies, and innovation aiming to help people and to mitigate the spread of disease. The current situation has not only spurred digital solutions, but also innovative ways to uphold public health safety. Besides the countless innovations in remote working, digital tracing, and 3D printing of medical equipment, other more surprising innovations have made it to the market, such as antiviral fabrics and facemasks,^{12, 13} appliances for opening doors without physical contact,¹⁴ and smartbands to avoid unconscious facial touching.¹⁵ Countless robots have been developed, doing jobs ranging from reminding people in Singapore to keep social distancing to delivering food and handling multiple hospitals chores.¹⁶

WHAT HAPPENS NEXT?

A crisis must often be observed in retrospective to fully understand the consequences and changes it led to. Although COVID-19 is still raging across the globe, we can already see a window of opportunity to radical change, especially within healthcare, where adoption of digital strategies and collaborations across borders is essential. It is important that stakeholders and decision makers grab this opportunity and strike while the iron is hot and that the flourishing digital solutions inspire decision makers to provide the right regulatory framework and strategic foresight for further implementation in a post-COVID-19 world.

'As we grapple with the tragic COVID-19 pandemic, it is enlightening to see collaboration in multidisciplinary fields, sometimes between otherwise competing companies, and innovation aiming to help people and to mitigate the spread of disease.'





THE PATH TO PERSONALISED HEALTH

PHOTO GUILIA FILIDEI & JAMES HEMING

As populations continue to age and become more diverse, their needs are becoming more varied, as is the global burden of disease. With the rise of advanced medical and communications technologies like genomic sequencing, 5G networks, and telemedicine, it is becoming easier to access quality healthcare and provide forms of treatment and disease prevention that are both more specialised as well as more holistic and integrated. These developments, coupled with increasing demands from individuals for more convenient and effective health services, are putting pressure on the entire health landscape to change and are driving a fundamental transition in how health and healthcare are understood, delivered, and experienced around the world.

DEFINING PERSONALISED HEALTH

The emerging personal paradigm shift in health has been acknowledged for years, but it has been called by many names: precision medicine, personalised medicine, precision healthcare, personalised healthcare – the list goes on. All these terms suggest a shift towards individualisation in health and healthcare, but approach this development in different ways, which often makes the shape of this development unclear. For example, the World Health Organisation's Regional Office for Europe offers the following definition of 'personalised medicine':

Personalised medicine refers to a medical model that uses the characterisation of individuals' phenotypes and genotypes to tailor therapeutic strategies for the right person at the right time, to determine predisposition to disease and to deliver timely and targeted prevention. Genomic and nongenomic biomarkers should enable the identification of patients who are more likely to respond to therapy and those most likely to experience side effects.¹⁷

The World Economic Forum offers a somewhat similar definition under the banner of 'precision medicine':

Many drugs and medical treatments have been developed using a "one size fits all" approach, which can lead to ineffective treatments for specific people or populations. Precision medicine offers the opportunity to tailor disease treatment to a specific person, by taking into account their genetic and biological make-up, the environment in which they live, and how they live their life. Fourth Industrial Revolution technological advances – such as increased computational capacity, sophisticated digital information platforms, and large amounts of genetic and biological data – are changing the players involved and the way in which health and healthcare systems function. A more tailored approach to screening, diagnostics, treatment, and cure can improve outcomes and potentially lower costs. Governments, industry, academics, civil society, and patient groups need to collaborate to ensure that the whole of society is able to benefit from rapid advances in technology and precision medicine.¹⁸

Another important aspect of these different, yet related definitions, is that they (like the one from World Economic Forum) often centre on treatment and the role of technological innovation in driving future developments in health. Although treatment is, and will undoubtedly remain, a core focus for and responsibility of health systems and care providers, preventive services are also fundamental components of the emerging health paradigm. Focusing on treatment alone risks proposing health as only the absence of disease rather than a state of wellbeing that can be maintained through prevention. Seeing health as the best possible quality of life and wellbeing over the course of a lifespan requires a focus on both treatment and prevention. A definition that reflects the full range of changes occurring in the health landscape hence requires a broader conception of health as something that is attained and maintained through both treatment and prevention.

Moreover, while technology is indisputably crucial to the development of new capabilities in healthcare, technology alone is not enough to drive a paradigm shift in health. A fundamental change in health is driven by a confluence of factors including governance, regulations, citizen engagement, and technology. This point has been illustrated well by the ongoing COVID-19 pandemic. Many of the technological solutions that helped healthcare systems contain the spread of the disease and maintain standard operations, such as contact tracing and telemedicine, have existed for years, but it took changes in policy and regulation as well as new demands from citizens to implement and utilise them to the fullest extent possible.¹⁹

A narrow focus on technology places limitations on how personalised healthcare can be envisioned in less resource-rich jurisdictions, where infrastructures are underfunded or non-existent and capital for investing in and implementing new technologies is scarce. Rwanda provides an example. Though the nation lacks an advanced digital health infrastructure, the small African country has - in collaboration with a digital health company - still managed to establish a remote personalised care infrastructure providing both treatment and prevention services using the existing mobile phone network. Rwanda is not developing and implementing new cutting-edge technologies, but rather implementing existing technologies in a novel way to provide and improve health services for its citizens: health innovation without tech innovation.²⁰ The emerging health paradigm, then, must be understood as a holistic development with elements other than the purely technological.

While the many definitions of the emerging health paradigm show that many organisations are actively thinking about the future of healthcare, this on the other hand indicates that there may be competing visions for how it should be achieved. To reinforce the developments that are driving the future of health as much as possible, it may be helpful to propose a broad definition around which a far-reaching consensus can be built. With a broad common vision, the collaboration that is needed to drive the future of health may be more easily achieved. With this in mind, we propose the following definition for *personalised health*:

A shift from one-size-fits-all treatment of disease to maintaining a high and healthy quality of life throughout life by applying the right health interventions for the right person in the right place at the right time.

An ideal personalised healthcare system involves the collection and analysis of data at scale and the integrated use of tools and services to tailor prevention, diagnosis, treatment, and follow-up to each person, simultaneously cultivating both individual and population health.

This definition is based on a review of definitions used by a wide range of public and private institutions that study and work to advance the emerging health paradigm, from the World Economic Forum and the European Union to pharmaceutical industry specialists and individual clinics. While these definitions use varying terms such as personalised medicine, precision medicine, and personalised healthcare, we use the term *personalised health* to place an emphasis on a holistic understanding of the new health paradigm. Rather than focusing solely on the treatment of disease and clinical care activities, this definition highlights that maintaining good health throughout life and the general prevention of disease also are key aspects of the future health paradigm.

Personalised health by no means excludes public health. While increasingly large data sets make it possible to provide effective, evidence-based care for individuals, the same data can also provide population-level insights that are useful for public health. Through the study of socioeconomic and behavioural data, it may become easier to identify vulnerable population segments and develop more tailored responses to their health challenges and needs.

A VISION FOR PERSONALISED HEALTH

By breaking down the proposed definition of personalised health into several components, we lay out a clear vision for the future of healthcare and its implications for individuals, organisations, and societies around the world.

Personalisation

The one-size-fits-all model of healthcare is being increasingly challenged as demands from individuals for more convenient and tailored health services grow and expanding digital infrastructures and technological solutions make such services possible. The largest driver of this may be rapid advancements in genomics and other '-omics', which are shedding an entirely new light on how biology is understood and how individuals respond to certain health interventions. This is covered in greater depth in "New Systems Biology" on page 20.

Prevention

The emerging health paradigm is moving away from the current treatment-centric approach to healthcare towards an approach that emphasises maintenance of health and prevention of disease. With non-communicable diseases making up around two-thirds of the global burden of disease today,²¹ healthcare systems are increasingly pressured to offer preventive services that can improve citizens' quality of life while keeping rising health expenditures in check. At the same time, private service providers are beginning to incentivise prevention for individuals for the positive impact it has on the cost of long-term care. American life insurer John Hancock's Vitality Program, which gives policy holders that provide proof of a healthy lifestyle better policy options and consumer rewards, offers an example of the growing role of prevention in the private sector.²²

Point of care:

time, manner, and place

Ensuring greater personalisation and prevention in health requires that services and care be offered and delivered at the right time and in the right way to meet the specific needs of individuals and their surroundings. This entails a transition in the physical aspects of healthcare and health service delivery. Points of care, which have traditionally been fixed and centralised physical locations like hospitals and clinics, are becoming more transient, mobile, and decentralised. With increased usage of telehealth and mobile health solutions as well as smartphone and wearable technology, individuals themselves are becoming points of care and, in the process, are contributing to the shift towards person-centric models of care.

Data

Data of all kinds – biological, behavioural, administrative, etc. – are the fundamental enablers of personalised health and health systems. Without data and, crucially, methods of analysing, sharing, and actively learning from data, a transition to personalised health will not be possible. This point is covered in greater detail in the article "We Share Data" on page 42.

Integration and interoperability

Personalised and preventive health is driven by integration and interoperability, which, in the broadest sense, is the ability to share information such that people and systems can effortlessly understand and learn from it. This applies not only to data interoperability, which is needed to create the massive data sets that enable predictive and preventive care, but also to cross-border and crossdisciplinary learning and collaboration, which will help integrate health systems and provide more opportunities for sharing knowledge and best practices both within and across countries.

Context-appropriate care

Societal conditions, technological capabilities, and cultural approaches to health vary greatly around the world, which will have significant impact on how the transition to personalised health manifests in different countries and regions. For this reason, the

broad definition of personalised health provided above does not seek to emphasise or advocate for specific practices, technologies, tools, or services.

GETTING TO PERSONALISED HEALTH

The transition to personalised health involves a multi-pronged approach in which states, health systems, private organisations, and society all play crucial roles. While many aspects of the transition and exact roles and responsibilities of these institutions, organisations, and actors will vary greatly in every national or regional context, it is possible to identify several generalised building blocks for realising personalised health.

Health as an investment – not a cost

A key to initiating and sustaining the transition to personalised health is to shift the mindset of policymakers from seeing health as a constant or rising cost to health being a long-term investment. The focus of personalised health on more holistic and preventive care requires that health be understood as not just the absence of disease, but rather sustained wellbeing and a high quality of life. This in turn implies a broad approach to health investment, covering not only traditional healthcare services, but also services and infrastructures that support wellbeing, such as programmes for community and mental health. From a strict policymaking perspective, the 'Health in All Policies' approach, which encourages policymakers to evaluate the health-related impacts of all domains of public policy, provides a strong example of this mindset.²³

Institutional and organisational partnerships

The development, implementation, and monitoring of successful personalised health services relies on partnerships that span boundaries. This includes improved cooperation and working protocols between organisations and institutions within countries, between public and private entities, and – especially – across national and regional borders. State institutions, the health industry, and citizens all need to have a role in shaping policy for the transition towards personalised health. By identifying areas of common interest, diverse coalitions can work to ensure that a given jurisdiction's approach to personalised health is reflective of the institutions, organisations, and citizens that will support and benefit from it. Without increased collaboration, knowledge, expertise, and data will continue to be kept locked in silos, and potential partners will remain competitors, stifling progress towards personalised health.

Citizen engagement and empowerment

To truly put the 'person' in personalised health, people need to be actively engaged in and empowered to take control of their own health. Personalised and preventive health services may in some instances require higher levels of health literacy, which means that individuals need to be provided with the knowledge to manage their health better and feel that their engagement with their health and health-related matters is meaningful, effective, and secure. In many cases, this may take the form of improved digital literacy and increased openness towards data sharing.





systems biology



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n order to achieve personalised health we must know the biological makeup of each individual. Since the beginning of the 21st century, there has been a paradigm shift in the way we approach biology. We have moved from a reductionist approach, which dissects biological systems into their constituent parts, towards a more holistic approach termed *systems biology*. Systems biology is a strategy or way of thinking about how to research biological organisms. It aims to understand the full picture of the extremely complex biology composed of dynamic and interrelated genetic, protein, metabolic, and cellular components with the help of biology, mathematics, and computer science.²⁴

Systems biology is an emerging field that combines several branches of biology, including bioinformatics and the computational and mathematical analysis of the generated data. It generates huge amounts of often complex data and even when experts analyse and understand the data, the general public doesn't necessarily understand what they mean for them and their health. The communication of results is crucial, so that a patient understands that e.g. a risk score is not equivalent to actually getting the disease later in life and has the ability to easily decode and understand the information acquired by commercially available products.

GENOMICS, THE FATHER OF OMICS

The addition of 'omics' to a molecular term, as for 'protein' to form 'proteomics', implies a comprehensive or global assessment of a set of molecules, e.g. genes, proteins, or fats. Combining omics provides a more complete molecular perspective of biological systems compared to traditional approaches. The oldest omic is genomics, which is the study of the genes. Genes influence what we look like on the outside and how we work on the inside. Examining the genetic background is of great importance for identifying individual mutations and/or variants underpinning pathways that distinguish health and disease. It is carried out by genomic sequencing, which reveals how the genetic components (the nucleotides of the DNA) are put together in each gene.

The Human Genome Project, completed in 2003, revealed that there are approximately 20,000 genes in the human genome. The scientific community believed that precise information about the human genome would reveal the origin and mechanisms behind most diseases. Unfortunately, this turned out to not be the case, since most diseases are polygenic, meaning they have several underlying mechanisms, not all of which are imprinted in the genome. Even so, genomics is widely used in clinical settings today. It is still expanding our knowledge and understanding of genomic disease and has helped transform medicine. Genetic risk factors and strengths can be identified in advance, and the prevention, diagnosis, and treatment of diseases can be targeted to have the best effect on individuals. In medical research and clinical practice, genomics focuses on identifying genetic variants associated with disease, responsiveness to treatments, or future patient prognosis, e.g. through a genetic risk score. Polygenic risk scoring can quantify the probability of the onset of diseases such as cardiovascular disease, and intervention can then be staged to prevent the disease form developing.25

Pharmacogenomics is a branch of genomics and is the study of

how genes affect a person's response to drugs. It is well known that the same drug can have different effects in different individuals due to their genomic background and living habits. Genetic information can be used to assign drug doses and reduce side effects and is hence an important aspect of personalised medicine.²⁶ Genetic testing is used to decide the most affective and optimal treatment for individual patients.²⁷ More than 100 different drugs approved by the US Food and Drug Administration (FDA) are now packaged with instructions that tell doctors to test their patients for genetic variants.²⁸ New treatments for solid tumours are emerging, based on genomic information and vaccine development. Companies are producing tailored vaccines specifically targeted to the patient's tumour. Once injected into the patient, the vaccine has the potential to help the patient's immune system to better recognise the cancer cells and destroy them.²⁹

Two decades ago, full genome sequencing took several years and cost at least USD 500 million. Since then, the cost development has broken Moore's law, which can be formulated as saying that the cost of computing power halves every two years (see graph). The cost of genome sequencing has however stagnated in recent years. Today, the price of full genome sequencing is less than USD 1,000 and takes a day or two.³⁰ This decline in cost has allowed for wide-spread use in healthcare and enabled private companies like 23&me to build a commercial business on genetic sequencing. These businesses offer everything from ancestry to disease screening and health planning based on the information encoded in your personal DNA.³¹

MULTI-OMICS AND THEIR POTENTIAL

In the wake of the birth of genomics came other omic disciplines, which investigate e.g. RNA, proteins, metabolites, fats, and bacteria. The omics are important as they can identify new molecular pathways and targets for treatment, and they can help when selecting patients for clinical trials, in drug repurposing and reconditioning, and in the creation of experimental and predictive models for human health and disease.³² While the genome is largely static, the other omics are dynamic and vary across time and environments, providing a snapshot of real-time health status. This is useful in diagnostics, e.g. when using liquid biopsies. Liquid biopsy is a non-invasive biopsy technique, done on a sample of blood or urine to test for biomarkers (biomolecules that can identify or predict disease) or e.g. pieces of DNA from a tumour that are circulating in the blood. The major advantage of liquid biopsy analysis is that it is minimally invasive and can be serially repeated, thus allowing extracting of information from the tumour in real time.³³ Moreover, the identification of predictive biomarkers in peripheral blood can monitor the response to therapy in real time and holds a substantial potential for novel approaches in the therapeutic management of cancer patients.³⁴

Advances in these areas are only in their infancy. They include more measuring techniques, and data are complex and heterogeneous, which complicates and limits the application. AI promises to further enhance our ability to interpret and understand omic data and thereby enables the proliferation of applications. Nevertheless, combining different data types and using 'multi-omics' hold great promises, and there is no doubt that multi-omics will

COST TO SEQUENCE AN ENTIRE HUMAN GENOME OVER TIME IN USD



play a great role in future diagnostics.³⁵ A proof-of-concept study shows that prospective tracking of health using multiple omics could highlight indicators of disease prior to the development of a disease and that beneficial changes in lifestyle might help to prevent it.³⁶

GENETIC ENGINEERING – A WAY TO FIX SICK GENES AND TREAT DISEASE

Based on genetic information and improvements in biotechnology, advances within genetic engineering has accelerated. Gene therapy is a therapeutic area of treating genetic disorders by using a number of techniques of genetic manipulation. The number of clinical trials using gene therapy increased by 17% from 2018 to2019, and gene therapies have been approved in therapies for several different disease, including some cancers.³⁷

Genetic engineering is carried out by various molecular techniques that aim to either replace a mutated gene with a healthy copy of that gene, by inactivating or 'knocking out' a mutated gene that is functioning improperly, or introducing a new gene into the body or specific cells to help fight a disease. Traditionally, the delivery of a gene is carried out using a carrier called a vector, genetically engineered to deliver the gene. Certain viruses are often used as vectors because they can deliver the new gene by infecting cells.³⁸ This technology is used in the currently very exiting Chimeric Antigen Receptor (CAR-) T cell therapy, where gene therapy is used to deliver a gene that enables immune system cells to attack cancer cells.

Gene therapy is extremely expensive, with the top ranking at the astronomical price of over USD 2.1 million for a single use. Other, less expensive FDA-approved treatments lie between USD 375,000 and USD 875,000.³⁹ Adoption of the full range of gene therapies could be relatively slow unless costs come down due to competition or new financing models. Overall, gene therapies for monogenic diseases, like sickle cell anaemia, are likely to be adopted earlier than those for polygenic diseases, which are more complex.

Recently, a different technique has gained much attention. CRI-SPR-cas9 is a relatively new and, more importantly, inexpensive technique that can edit genes by adding or deleting genetic material in our DNA. At present, clinical testing is carried out for sicklecell anaemia, where the CRISPR technology is used to reprogram damaged red blood cells back into to their original healthy state.⁴⁰

Genetic engineering is also used for 'gene drives' where it is used to alter a specific genetic variant to be passed from parent to offspring at a higher than normal rate. Currently, testing is carried out with vector-borne diseases like malaria or zika viruses, which are transmitted by mosquitoes. Here, a gene drive can make the mosquito immune to infection by the parasite or make it sterile so that it cannot produce offspring. These changes could reduce transmission to humans. Caution should be made, though, as we currently do not know what long-term consequences this might have on the ecosystem.⁴¹

STEM CELLS – AN OLDIE BUT A GOODIE

As we are able to manipulate genes, we are also able to manipulate cells, e.g. stem cells. Stem cells are undifferentiated human cells that can develop into many types of cell. The versatility of these cells has evoked great promises for their application in medicine, thereby providing hope for untreatable diseases. Scientists have been working with embryonic stem cells since the 1950s in order to understand how disease occurs and possibly use them to reproduce new tissue and replace damaged cells; a field known as *regenerative medicine*.

In 2006, scientists learned how to reprogram adult cells into becoming stem cells, thus circumventing the ethical issue of using embryonic stem cells.⁴² Stem cell research is intense and has greatly improved our understanding of how organs develop and what happens in the process of disease development. The application of stem cells holds genuine promise for certain disorders, although the current practice is still rather limited due to many challenges, such as rejection by the patient or the risk of developing cancer.⁴³ Currently, the main application is in bone marrow transplants for blood diseases such as leukaemia, lymphoma, and myeloma. New treatment may be on the horizon, as studies also show that it is possible to grow skin for burn patients⁴⁴ and the cells responsible for colour vision and light sensitivity, the latter showing the potential to treat blindness due to macular degeneration.⁴⁵ The list for possible practises of regenerative medicines spans widely, from Parkinson's disease and sclerosis to type I diabetes. A PubMed search for "stem cell therapy" shows that in 2019, more than 15,000 scientific articles were published on the subject, showing intense focus and progress within this field.

ORGANS-ON-A-CHIP AND 3D BIOPRINTING

Taking it a step further than just cells, we now have the opportunity to build biosystems and complete organs using 3D bioprinting.⁴⁶ An organ-on-a-chip is a micro-scale system used for mimicking the human body environment. The goal for organ-ona-chip is to develop human tissue models for disease modelling and drug testing.

Bioprinting is a technology that can produce customised, 3-dimensional structures composed of biological and non-biological materials. Developments in the field of bioprinting are being driven largely by the medical needs of ageing populations, increasing unmet demand for organ donors, trends towards non-animal testing on therapeutics using 3D cell culture platforms, clinical needs in wound care, and joint repair and replacement surgeries.⁴⁷ Besides direct applicability in regenerative medicine, 3D bioprinting is increasingly used for pharmaceutical development and drug validation as analogues for toxicity testing in drug screening, disease modelling for drug discovery to minimise the use of animal testing, and for patient-specific drug screening and precision medication dosage.^{48,49} Printing of entire organs is on the horizon, eventually for transplants, but also for teaching, planning, and practice for procedural surgery.

NEUROPROSTHETICS – THE WAKE OF DEAD LIMBS

At the interface between biology and technology lies *bionics*. Neuroprosthetics are hybrid bionic systems that link the human nervous system to computers, thereby providing motor control to an artificial limb or restoring lost sensory function. Already established in this field is the cochlear implant for hearing loss and bionic vision. 50,51

Neuroprosthetics can restore motor control for different conditions. Patients with a physical limb loss can use a myoelectric device that reads electric signals from the muscles of a remaining limb to control a prosthetic limb, (left side of figure below) an example being the Hero Arm from Open Bionics.⁵² Patients with limb paralysis due to nervous system damage can use muscle stimulation, where signals are transmitted from the brain via a neural implant or a headband. These signals are converted to electric stimulation of muscles to control existing limb or a brain-controlled exoskeleton (right side of figure below).⁵³ Scientists at ETH Zürich have even created sensors in bionic feet that sends signals back to the tibial nerve in the leg, enabling the patients to feel their prosthetic feet in real time.⁵⁴

This technology is advancing rapidly, and bionic interfaces are used in many settings other than neuroprosthetics, such as the diagnosis and treatment of brain diseases and measurements of brain activity. As innovation and technology advance at unprecedented pace, we will likely see many applications that seemed impossible just a few years ago and might seem implausible today. With AI emerging in most fields, technology will play a larger role in health than ever before. The figure illustrates examples of Neuroprosthetics controlling an artificial limb, left side, through either electrical signals received from the muscle of the arm or from the brain either through a neural implant or a headband. Right side illustrates signal transduction to a paralyzed limb where brain signals are converted to electric stimulation of muscles to control existing limb or a brain-controlled exoskeleton.

Modified from McKinsey Global Institute analysis





NEW SYSTEMS BIOLOGY CASES

Stem cell therapy –regenerating the damaged eye

The Holoclar^{*} system uses eye stem cells to heal and repair damage to the eye caused by physical or chemical burns, which can cause the cornea to deteriorate. Undamaged cells are taken from the limbus of the eye and grown in the laboratory using cell culturing techniques which produces a sheet or cornea which can be transplanted back into the eye and restore sight. The technique was approved by the European Medicine Agency Commission in 2014⁵⁵.

Stem cell therapy, re-growing damaged nerves

Scientist have created a special matrix what have allowed them to differentiate stem cells into nerve cells, that when transplanted into a rat model of Parkinson's disease, eased the animals symptoms by replacing those nerve cells lost to the disease. After 18 weeks, researchers found that newly differentiated, dopamine-producing nerve cells had started to spread around the transplant site, replacing those cells the animals had lost over the course of the disease⁵⁶.

Personalised vaccines to attack cancer cells

By taking a biopsy of a patient's tumour and using this unique genetic information from their own tumour in combination with AI, scientists can design invidualised vaccines to activate the patient's immune cells to better recognize cancer cells, attack and destroy them. Studies are currently in clinical trials and look promising especially in combination with other treatment modalities⁵⁷.

Gene therapy – induction of new genes to help the cell combat disease

In Chimeric Antigen Receptor (CAR-) T cell therapy, the patient's immune cells, called T cells, are taken from a blood sample and genetically engineered by the use of a vector, to attack cancer cells. Large numbers of the genetically engineered cells are grown in the lab and infused into the recipient patient where the blood cells will start to eliminate the cells of the tumour⁵⁸.

CRISPR-cas9 to the rescue to fix a broken gene

Sickle cells anaemia is an inherited disease that causes deformation of red blood cells making them prone to disruption of the blood flow. Doctors can reprogram the blood cells to foetal haemoglobins by using CRISPR-cas9 to repair the defect gene that causes the disease. Clinical trials are currently ongoing⁵⁹.

Multi-omics in liquid biopsies

Liquid biopsy uses noninvasive blood test to assess tumor heterogeneity and evolution in real time. It looks for tumor components in the blood circulation, such as circulating tumor cells (CTCs) and circulating tumor DNA (ctDNA), to provide tumor-specific information. By detecting multiplex tumor biomarkers, including nucleic acids, proteins, carbohydrates, and other tumor-derived substances, liquid biopsy helps with early tumor diagnosis, tumor evolution monitoring, and prognosis prediction⁴⁰.

Genetic information before conception

Carrier screening is a genetic test to determine if a healthy person is a carrier of a recessive genetic disease. It can be performed on individuals planning to start a family to determine if they are carriers to of recessive disease that could be passed on to their baby. Genespeeks, a private company, takes DNA from sperm donors and recipients to create "virtual babies" or in-silica offspring that can be screened for genetic diseases.



2020 VS 2030

PHOTO HAYDAN AS-SOENDAWY

2020 / 2030

Decrease in prevalence of new HIV infections globally	
Increase in total global population in billions	
Increase in median age in years globally	30,9 / 33
Decrease in mortality under 5 years old per 1000 live births globally	
Increase in life expectancy at birth globally	
Increase in prevalence of obesity in billions globally	
Increase in deaths related to cardiovascular diseases in millions globally	
Increase in deaths related to lung cancer cancer in millions globally	



Emerging health technology

n the coming decades, advances in health technology will be an integral part of what is often referred to as "the fourth industrial revolution" (4IR). The first industrial revolution was mainly characterised by steam and water power, the second by oil and electricity, the third by computers and the internet, and the fourth will be based on 'smart' technology such as robots, artificial intelligence, and the Internet of Things, as well as biotechnology and nanotechnology. This merging of physical, digital, and biological systems has far-reaching potential to transform health and medicine due to comprehensive advances in genomics, genetic engineering, synthetic biology, nanotechnology, data science, AI, and robotics, promising breakthrough diagnoses and therapies, including precision medicine and medical cures.

According to Klaus Schwab, founder of the World Economic Forum (WEF), who introduced the idea of the fourth industrial revolution, 4IR "will not only change what we do but also who we are by its effect on our identity and all the issues associated with it: our sense of privacy, our notions of ownership, our consumption patterns, the time we devote to work and leisure, and how we develop our careers, cultivate our skills, meet people, and nurture relationships. It is already changing our health and leading to a 'quantified' self, and sooner than we think it may lead to human augmentation. The list is endless because it is bound only by our imagination."

While 4IR will have innumerable impacts on how we experience and deliver healthcare as well as manage our own health, there is a few underlying technologies that sets the premise for the development:

AI

Artificial intelligence (AI) is a branch of computer science concerned with the development of systems that can perform tasks usually associated with human intelligence, such as problem-solving, reasoning, and recognition. The possible applications of AI are many, from administrative tasks to diagnosis and drug development. Different applications of AI are already being applied in healthcare today and are widely used in screening, diagnostics, and imaging, as well as in digital administrative task and the engagement of patients. AI will without a doubt play a much larger role in the future, especially in connection with *machine learning*, a process where an AI learns to solve complex problems by being trained on thousands of examples.⁶¹ The adoption of AI by pharmaceutical and medical device companies as well as healthcare providers has led to new partnerships, new product development, and mergers. The market for AI technology is at an all-time high with USD 2.5 billion spent in 2018, and public and private sector investments in healthcare AI is expected to reach USD 6.6 billion by 2021 according to some estimates. Even more staggering, it has been predicted that AI applications may result in annual savings of USD 150 billion by 2026.62

However, it is important not to use AI uncritically. Biases are, for example, a major concern. Algorithms are fed a huge amount of information and rely on previous knowledge. If algoritms are fed with incomplete information that lack diversity in gender, background, or age, they will become biased or unreliable. Furthermore, technologies such as algorithms, robotics, and quantum computing differ radically and hence present radically different challenges. In addition, many of these fields are developing so rapidly that governance frameworks and regulation must deal with a constantly moving target.

CONNECTIVITY

We are more connected than ever before. Two thirds of the people in the world today own mobile devices, with almost half owning smartphones (a 40% increase since 2016), and it has been forecast that by 2025, 72% of all internet users will solely use smartphones to access the web.⁶³ Before long, the 5G wireless network will be serving this whole ecosystem of digital health. It will improve connectivity and integration across networks and devices with massively increased capacity and higher speeds. It will allow for more reliable communication and enable telesurgery, remote consultation, and remote monitoring, leading to a decentralisation of healthcare models.

The Internet of Things (IoT) is a term used to describe the global system of interconnected devices that collect and transmit data through the internet, telephone networks, Wi-Fi, Bluetooth, NFC, and more. The *Internet of Bodies* (IoB) is an extension of IoT where the human body is connected to a network through devices that are ingested, implanted, or otherwise connected to the body. Once connected, data can be exchanged, and the body can be remotely monitored and even affected. Healthcare providers are already exploring the potential of telemedicine; monitoring and treating patients remotely via Internet-connected sensors and medical devices. It is hoped that telemedicine will prove especially valuable in the treatment of chronic conditions that affect the elderly, allowing senior citizens to receive medical check-ups in the comfort of their own homes, and bring medical care to communities in remote locations.

BIOTECHNOLOGY

Biotechnology covers a wide range of technologies including genetic engineering, the use of stem cells, artificial organs, and bioinformatics such as genome sequencing and analysis. While biotechnology is discussed in the previous pages, more examples are provided in the following, where we present concrete examples of technological developments in all of the above areas that have a high potential to impact how health is experienced, delivered, and managed over the next three decades.

The following pages presents emerging healthcare technologies in the short, medium, and long term:

Tech examples

Short term





DISTRIBUTED LEDGER TECHNOLOGY

The use of distributed ledger technology (DLT), such as blockchain, holds great promise in relation to the sharing of data. Blockchain is a way of organising data so that transactions can be verified and recorded through decentralised networks. Every member of the community holds identical, unchangeable records of all transactions conducted, enabling transparency and security. Records are encrypted to provide an extra layer of security. DLT can facilitate trust for actors who do not necessarily know each other. In a distributed ledger, the task of creating trust is shifted to the technology and the distributed network of users without a need for intermediaries.⁶⁴ A blockchain approach in healthcare can give individuals the data management tools they need to become more health literate, engaged, and proactive as they take charge of their own care. The patient can play a role in defining when certain elements get shared and how widely that sharing goes.

The Estonian government is working in cooperation with the Estonian company Guardtime to secure the health records of Estonian citizens using blockchain technology. Citizens carry smart cards through which they can access over 1,000 online government services including viewing their health records.⁶⁵

DIGITAL MEDICAL TATTOOS

A digital or electronic tattoo is made with nano-ink that allows printing electronic devices for biomedical applications. Examples are microelectronic health monitors, an extension of wearable technology. They are essentially thin flexible patches of rubber with microelectronic biosensors that wrinkle and stretch without breaking. They can be printed directly onto the skin, with the ink drying in less than two minutes. When the 'tattoo' is attached to the skin, tiny electrodes can record information about the wearer and transmit it to smartphones or other connected devices, just as wearables and smart watches do today. They can operate without batteries, as they can receive energy through electrophysiological processes. These small, non-invasive devices could allow healthcare experts to monitor blood glucose levels, blood pressure, blood alcohol levels, heart activities of premature babies, and brain activities, but also help diagnose heart rhythm problems, sleep disorders etc.⁶⁶ They will have application for the Internet of Things, smart devices, and more.^{67, 68}

In Sep. 2019, the University of San Diego started their second clinical trial using an epidermal sensor, a medical tattoo, for continuous glucose measurements. They started the development of their needleless glucose monitor back in 2016 but unfortunately failed in their first design, which lacked accuracy at detecting glucose levels compared to a traditional invasive finger-prick glucometer. However, improved technology led to initiate a new clinical trial expected to be completed by 2021.⁶⁹

SMART CONTACT LENSES

Delivery of drugs released from a contact lens, continuous glucose monitoring, and measurements of eye pressure are just some of the possibilities offered by smart contact lenses. Smart contact lenses can monitor the physiological information of eye and tear fluids, thereby providing real-time, non-invasive medical diagnostics. The smart contact lens device is built on a biocompatible polymer and contains ultrathin, flexible electrical circuits and a microcontroller chip for real-time electrochemical biosensing, on-demand controls drug delivery, wireless power management, and data communication.⁷⁰ Looking even further ahead, these sensors might have a tiny retinal display for augmented reality technologies. The global smart contact lenses market is projected to reach USD 2,860.50 million in 2025.⁷¹

Glaucoma is caused by abnormally high eye pressure and is the leading cause of irreversible blindness. Using a different technology from the one described above, Stevens Institute of Technology has developed a smart contact lens called Ocularity. The device, which has embedded pressure sensors made from carbon nanotubes, is designed to continuously monitor intraocular pressure in glaucoma patients, charting the peaks and valleys of eye pressure fluctuations throughout the day. The contact lens wirelessly transmits the signal to the doctor who can react to changes proportionately.⁷²

INGESTIBLE SENSORS

Ingestible sensing capsules are a fast-emerging technology that can truly impact health, nutrition, and clinical areas. These ingestible devices are non-invasive and therefore very attractive for consumers. A pill containing a form of sensor is ingested and moves through the gastrointestinal tract while collecting information that can be transmitted to a phone or other device. The output provides invaluable information about the state of gut health and disorders as well as the impact of food, medical supplements, and environmental changes on the gastrointestinal tract.

Scientists have created an ingestible sensor that can detect intestinal bleeding. It is a pill containing a genetically engineered, harmless bacterium that glows in the dark when it encounters heme, the iron-containing molecule in blood. The glow can be captured by a custom phototransistor and transmitted as a signal to a microprocessor, which sends the signal to an app.⁷³ Hopefully, this technique will be expanded to measure other gastro-intestinal molecules that can reveal health status.

CHATBOTS

A chatbot is a computer program or mobile app designed to stimulate conversation with human users. In the future, a chatbot could be the very first encounter with a health care professional for most people. It can wake you up in light sleep, remind you to take medicine because pollen concentration is high, and when you need to see your doctor, you can screen your symptoms with a smart algorithm chatbot before your visit. Chatbots are already being used to address specific issues in health care, such as to help reduce no-shows for examinations, which is a particular concern for less privileged patients.⁷⁴ Many kinds of chatbots exist, dealing with everything from helping with emotional health, information regarding cancer therapy, providing a personal nurse, and drug screening for breast-feeding mothers.⁷⁵

Vik is a chatbot designed to empower patients with breast cancer and their relatives. It responds to fears and concerns of patients with breast cancer using personalised insights though text messages. Studies have shown that through interaction with the chatbot, patients have an increase in medication adherence due to prescriptions reminders, and patients fell that the chatbot provide them with support and help them track their treatment effectively.⁷⁶

REMOTE MONITORING AND SAMPLING

Devices and platforms for remote monitoring are ever-increasing, with the necessity of such devices becoming even clearer in the wake of the COVID-19 pandemic. Uses for remote monitoring devices range widely, from continuous temperature monitoring to arrhythmia and ECGs, to providing sensor-guided exercise therapies to empowering patients and health professionals in real-world settings. With the use of these devices, patients can be taken out of the system and placed at home in comfortable soundings, with the security of constant monitoring and guidance from health professions.

The Danish company Qlife has developed a device for at-home use for analysis of blood samples, which measures biomarkers in a small, disposable capsules. The results of the sample are sent to the patient's doctor. The kit could one day be used to measure blood levels of specific medication to check if a drug is working. The company is currently teaming up with a Finnish company to provide a similar antibody test for SARS-CoV-2 and a coronavirus test.⁷⁷

DIGITAL THERAPEUTICS

Digital therapeutics can be considered a subcategory of digital health, composed of software-based therapies with proven clinical efficacy. Digital therapeutics deliver evidencebased therapeutic interventions to patients that are driven by high-quality software programs to prevent, manage, or treat a medical disorder or disease. They are used independently or in concert with medications, devices, or other therapies to optimise patient care and health outcomes.



BlueStar helps patients with type I and type II diabetes who struggle with managing the other aspects of their diabetes, including managing medication, food, activity, sleep, diet, and psycho-social factors. Patients are encouraged by more than 30,000 automated, tailored, and unique coaching messages. Users will take in real-time actions, including daily medication administration, physical activity, smart food choices, and psycho-social wellbeing, – based on recommendations provided by the program that are driven by clinical guidelines.⁷⁸

Medium term

20 YEAR ESTIMATE



OPTOGENETICS

Optogenetics is a novel field that combines light and genetics to control the activity of excitable cells and neural circuits, holding great promise for future uses in clinical settings. More specifically, optogenetics entails using genetic engineering to induce photosensitive ion channels in specific cells or neurons to activate these neurons by stimulation with light. Potential applications of optogenetics are evident in many fields, including medical science. By genetic manipulation of specific cells and the use of light, is possible to block pain signals which would be beneficial for patients that suffer from chronic pain. Other applications include treatments for heart failure, vision and hearing loss, bone repair, and neurological diseases.⁷⁹

Studies have shown that optogenetics can reduce brain damage that occurs after a stroke. Experiments on genetically modified mice with an induced stroke condition showed improvement in cerebral blood flow after repeated light stimulation. These studies suggest that optogenetics can be used to promote neurofunctional recovery after a stroke.⁸⁰

IN SILICO TESTING

In silico modelling, in which computer models are developed to model a pharmacologic or physiologic process, is a logical extension of controlled *in vitro* experimentation. It can circumvent the ethical use of animal testing as well as facilitating translation to human. The human-based computer models are fast, inexpensive, and potentially effective alternatives to experimental assays. In silico testing is made possible by the explosive increase in computing power available to the research scientist at a continually decreasing cost. The FDA predicts that more than half of trials in the future will be *in silico* trials.⁸¹

In silico testing has been used in several studies to predict which bacterial strains are resistant to antibacterial treatment. Based on screening for antibiotic resistance genes, the testing can predict which of the bacterial strains would be immune to antibiotic treatment and thereby suggest a different treatment regimen.^{82,83}

The Human Brain Project is the largest scientific projects ever funded by the European Union. Among other things, the project seeks to simulate how the human brain works, from abstract to highly detailed molecular and cellular models, to perform investigations that are not possible in the laboratory.⁸⁴

ARTIFICIAL ORGANS

So far, artificial organs have been poor substitutes for donor organs, but this looks to change in the coming decades. Promising research is being done in both bioartificial organs (based on living tissue from e.g. stem cells) and more mechanical artificial organs like heart pumps. With the waiting lists for donor organs growing, artificial replacement organs will be in high demand. In time, artificial organs may become as good as natural ones, or even better, and replacing worn-out natural organs with artificial ones may become routine for older people, no stranger than replacing an old dishwasher with a new, more ad-
vanced model. In the far future, nanomachines may be employed to gradually replace old organs with new ones inside the body, eliminating the need for surgery.

A promising way to produce bioartificial organs is through 3D-bioprinting, where different materials, such as scaffolding tissue and living cells, are combined in a 3D-printer until a finished product (e.g. an organ) is created. Research is being done today with printing skin and bone as well as cardiac, lung, liver, and neural tissue, and within a few decades, the printing of full bio-compatible organs may be possible.⁸⁵ As of May 2020, 13 patients worldwide have been implanted with the world's first fully electric artificial heart, the commercially produced Carmat, with a self-regulation system that adapts to the body's activity. With a patient survival rate of 70% for six months or until a suitable donor heart is found, Carmat is not yet as good as a real organ, but further development could make it or similar artificial hearts as good or better than donor organs – in particular if it is made by biocompatible materials that aren't rejected by the patient's immune system.⁸⁶

DNA NANOBOX DRUG DELIVERY

Scientists have learned to build tiny structures from DNA string through a process called 'DNA origami'. DNA origami objects are built from one long 'scaffold' of single-stranded DNA bound together with 'staples' that consist of hundreds of shorter strands. Staples have a specific base sequence that can only bond with corresponding sequences on the scaffold, causing the two to link, forming predetermined, compact, nanometre-scale structures of DNA. One such shape is a box that opens and closes in the presence of certain chemical 'keys'. These nanoboxes can be made to hold drugs, which are released in the presence of a chemical signature of cancer cells.⁸⁷

In 2018, nanoboxes carrying thrombin were tested in mice and Bama pigs. The thrombin was released near cancer tumours, cutting off blood supply to tumour cells and inhibiting tumour growth. In early 2020, Chinese scientists reported using a similar technique to create a 'precision-guided missile' that delivered the cancer drug doxorubicin directly to cancer cells.⁸⁸

BRAIN MONITORING

Scientists are exploring the possibility of directly translating language from patients' brains to computers. Brain-to-device communications, either through a surgically inserted neuro-prosthetic device or a headband that measures brain activity through the skull. Advanced brain signals-reading headset have been in development for a while, and it is currently possible to 'read' a patient's emotional state – something that can provide great assistance in therapy.

Elon Musk and his company Neuralink want to take it a step further. Musk suggests that in the future, the neurotech company will be able to solve all sorts of congenital diseases and brain disorders with a net of very tiny neuron signal-reading threads ('neural lace') that will be implanted in the brain by a robot. These threads are about a tenth the width of a human hair, roughly the size of a neuron. The goal is to monitor and selectively stimulate as many neurons as possible across diverse brain areas. Neuralink, Musk says, will effectively add a layer to the collaboration between the limbic system and the cortex in our brains – "a tertiary layer, which is the digital superintelligence layer."⁸⁹

AUGMENTED AND VIRTUAL REALITY

Augmented reality (AR) is a real-time view for a real-world environment that is overlaid with or enhanced by computer-generated sound, video, graphics, GPS data, or input we may not yet have considered. Virtual reality (VR) is a complete immersion experience that shuts out the physical world. Using VR devices, users can be transported into a realworld or imagined environment, such as the middle of a squawking penguin colony, ancient Rome, or the back of a dragon flying across a magical kingdom.

In a Mixed Reality (MR) experience, which combines elements of both AR and VR, realworld and digital objects interact. The use of AR and VR holds great promises in healthcare, such as aid in planning surgeries, helping patients with anxiety, helping Parkin-







son's patients walk, and help diagnose and monitor early onset of Alzheimer's disease.⁹⁰ Alzheimer's disease is usually diagnosed using traditional cognitive tests which cannot discriminate between anxiety, normal ageing, and Alzheimer's. A shortcoming of the traditional cognitive tests used to detect early symptoms of Alzheimer's is that there is no test for navigational impairment. To address this, scientists from the Department of Clinical Neurosciences at The University of Cambridge have created a VR navigation tests for patients. The test is conducted with the patient wearing a VR headset as they go through a navigation test in a simulation. To complete the course, the user must have a functioning entorhinal cortex, so in theory, those with early Alzheimer's disease would find it difficult to navigate in the test.⁹¹

Long term 30 YEAR ESTIMATE



ADVANCED MEDICAL NANOMACHINES

Medical nanomachines are mass-produced nanometre-scale machines (mechanical, electronic, or modified organic) that are injected into a patient's body for medical purposes. Nanomachines equipped with sensors and motors can find and destroy pathogens, remove atherosclerosis, or repair damaged bone or tissue. In time, it may be possible to create nanomachines that reproduce, or patients may be implanted with tiny 'factories' that produce medical nanomachines as needed, possibly in reaction to changes in body chemistry.

In 2020, a team of Chinese scientists devised the world's first artificial immune system from three types of DNA-studded gold nanomachines. With each nanomachine mimicking a different immune cell type, the system can recognise, neutralise, and remember an invading pathogen. When exposed to HIV DNA, the nanomachines reacted and destroyed 93% of the invader in 22 hours. When later re-exposed, the machines had learned and destroyed 97% of invaders in just 10 hours.⁹²

GENE EDITING

With in-utero gene therapy, it is possible to edit the DNA of children before they are born, replacing undesirable DNA strings with more desirable ones, with the changes being passed on to the next generation. A danger is that the genetic changes do not manifest in all cells, resulting in 'chimaera' where different body parts carry different genetic information. Once the method is fully developed, children could be 'designed' to carry genes for high intelligence, longevity, resistance to disease, and desirable cosmetic features. At first, such options are likely to only be available to well-off parents.

In 2018, He Jiankui of the Southern University of Science and Technology in Shenzhen reportedly used CRISPR to delete a gene called CCR5 in twin foetuses; something that would make the modified girls more resistant to HIV infections. The absence of CCR5 is also associated with high intelligence, success in school, and improved brain recovery after strokes. If successful, the twins will be the first people genetically designed to have superior traits.⁹³ China has locked down on the case, and the fate of the two girls is unknown.

GENETIC LONGEVITY TREATMENTS

Life expectancy has been growing steadily for at least the last century and a half, at a rate of roughly one extra year every five years or so. The trend is likely to continue in the coming decades, driven by several technologies. One process involved in ageing is the shortening of telomeres when cells reproduce, but it may be possible to reduce this effect through gene therapy.

Recent research has shown that non-genetically modified mice born with hyper-long telomeres showed significantly better health at old age by several parameters (including

reduced prevalence of cancer), and they lived 12.75% longer on average than normal mice, with an 8.4% increase in maximum lifespan.⁹⁴ In a 2012 experiment adult and old mice (1 and 2 years old, respectively) were given gene therapy that produced telomerase (the presence of which prevents shortening of telomers). These mice lived 24% and 13% percent longer than normal mice, respectively, with improved health.⁹⁵ In human terms, this corresponds to 20 and 10 years, and it is possible that similar treatment in humans could extend life to this extent (though it is equally possible that it will only extend life by a handful of months, as for the mice).

ARTIFICIAL WOMBS

In the future, it may be possible to dispense entirely with pregnancy, and foetuses can grow in artificial environments from conception to birth. This possibility is an extension of current technology. Human embryos have been grown in vitro (outside a womb) for up to 14 days, which is a commonly established ethical limit, but it is theoretically possible to go beyond that. At the other end, the technology for keeping prematurely born babies alive allows survival at an increasingly early stage, pushing the limits of viability to 22 to 23 weeks of gestation. In 2017, US researchers kept lamb foetuses alive in a 'biobag' of nutrients for four weeks, when the foetuses experienced normal development, a technique that could allow prematurely born babies to develop further with fewer complications.⁹⁶

If the limits of both these technologies are extended, they may eventually meet, and a human womb will become unnecessary for giving birth to a child. Ethical reasons for allowing this could be for disabled or diseased women to have children or as an alternative to surrogate mothers, which have ethical issues of their own. Anti-abortionists may see artificial wombs as an alternative to abortions: If a woman wants to end an unwanted pregnancy, the foetus could be brought to term in an artificial womb rather than being terminated. What the further fate of such a child would be is a separate ethical issue.

FULLY AUTOMATED SURGERY

Robot-assisted surgery has been around for quite a while, even allowing telesurgery, where a surgeon remote-controls a robot surgeon from another part of the world. So far, such surgery requires a trained surgeon to guide and supervise the surgery, but the goal is to eventually have robot surgeons that can handle operations without human assistance, expect perhaps oversight. Routine operations will come first, but eventually, robots may be able to handle any but the most innovative procedures unassisted.

The closest we have today to unassisted robotic surgery may be a robot developed by the Children's National Medical Centre in Washington D.C., which is specialised in sewing soft tissue after surgery. It was tested on pigs to sew together fragments of bowels by following indicative fluorescent markers. The procedure was supervised by surgeons, but no corrections were needed at the end. Robot assistance also allows human surgeons to perform otherwise impossible procedures, like removing a membrane one-hundredth of a millimetre thick, situated in the retina of the eye of a patient.⁹⁷

REGENERATIVE MEDICINE

Imagine if you lost a limb and then could regrow a replacement, like a lizard regenerating a lost tail. The purpose of regenerative medicine is to make this possible for humans. This is not quite as far-fetched as it may sound. Some nematode worms are even able to regenerate lost organs, and humans have been known to regenerate fingertips, including bone. Scientists are studying germ cells, the precursors to sperm and egg cells, which are the only cells in the human body with the potential to create an entirely new organism; an ability called 'totipotency'. They hope to learn how promote regeneration by unlocking the stem cell-like properties of other cell types. They have discovered that so-called 'Vasa' proteins play a role in determining whether a germ cells stays totipotent or becomes a specific type of cell, such as muscle, nerve, or skin cells. It may be possible to use this knowledge to turn on totipotency when wanted, e.g. for regeneration, and off when unwanted, as in the case of cancer.⁹⁸





The flipside of health technology

We sat down for an interview with Jeremy Lim to get his view on how emerging technologies and the COVID-19 pandemic will shape the future of healthcare. He is the co-founder of AMiLi, centred in Singapore and the region's first precision microbiome company. He is also Director of LIGHT, the global health institute for the NUS School of Public Health and teaches global health system reforms and digital health.





Which health technologies do you think will have the greatest impact in the delivery of healthcare in the future?

I think it will be a trinity of technologies, specifically deployed in combination, which will have the most impact. First would be the miniaturisation of various monitoring and diagnostic devices. Second would be advances in mobility and connectivity; i.e., the jump from 2G to 3G to 4G and now 5G. The third would be the increasing sophistication of AI and machine learning, both in the narrow and the general sense. Most technologies are overhyped, but there is a growing maturity among technologists, ensuring that use cases are more sharply defined. Additionally, I think that both developers and healthcare providers are coming to a mutual understanding of what technology can and cannot do. The interface between man and machine is particularly interesting, as I think we are starting to converge in a way that, at least for the foreseeable future, man augmented by machine will be superior to either man or machine alone.

How do you think the less advanced countries will look in terms of health technology in the future?

I am very optimistic about this. Similarly to the mobile revolution, particularly in India, where the Indians leapfrogged because they did not have the fixed infrastructure and were able to move into mobile immediately. India hence has some of the lowest mobile telecommunications prices in the world. I do believe that we will start to see this happening in healthcare as well, but in most of the emerging economies, it will be very patchy. Governments will likely not have the resources or the ability to launch national programs, and what might be far more likely to occur, at least initially, is that there will be very successful pilots done by local philanthropist and NGOs. These will hopefully get the governments to the tipping point for national roll out, as they can harness lessons from these.

While technology can be leapfrogged, in terms of human capital, every country will still need its bare minimum capacity of skilled physicians, nurses, and other healthcare professionals. In terms of privacy and other safeguards I think that developing countries run the risk of getting it wrong in two ways: Either there is so little regulation that there is a risk of massive data breaches and public backlash, or there is blind copying or adopting of regulations from the developed world, without placing them into the appropriate context.

You mentioned a bare minimum capacity in terms of human capital. Do you see any other minimum requirements?

Yes. One is the quality of the data sets, and the second is the sophistication of the algorithms that use them. The algorithms can frankly travel reasonably well in my view. One can rapidly adapt from the developed world, and technology talents globally can easily apply their skills to the developing world. However, it is the quality of the data sets that allow either novel algorithms to be built up or existing algorithms to be adapted relatively quickly. This is a bit more challenging, as governments need to invest both time and energy in creating these quality data sets and hopefully make them open source, so technologists can apply the data sets to their fullest potential. 'Garbage in, garbage out' is a notion we are all very familiar with. If data sets are incomplete and bring massive biases, then it can be harmful. Additionally, we cannot forget that there is also minimum capacity on the infrastructural side in terms of the coverage and reliability of networks and so on.

Moving on to the emergence of preventive health, why is there so little investment into prevention?

Developers and entrepreneurs reasonably go where the money is and there are only a few rare entrepreneurs that want to be 'category creators' like Steve Jobs. I suspect most would look at an existing pain point and find the path to monetisation, in the developing as well as the developed world. The bulk of the money presently is in therapeutics and treatment rather than in prevention. So, if you want more emphasis to be placed on prevention, then the economics have really got to work. Typical health systems will spend 85-90 percent of its total resources on curative services and maybe 10-15 percent on preventive and other services. Unfortunately, politics and economics, as they are now, are all against investing large sums of money into prevention.

Have you seen any good examples that show how a new business model could look in the future that also benefits citizens?

Yes, there is actually a great example called Reach52, a Singaporebased start up working in Asia, including the Philippines and Vietnam. It brings primary care, preventive services, and health education into rural communities, and as part of the business model it partners with for-profit companies and help insurers and pharmaceutical medical device companies understand the consumption patterns in these rural communities. This data is typically very hard to find, and the data monetisation helps to subsidise the services delivered.

What role do you think big tech has in the future of healthcare?

In my opinion, there is an optimistic and a pessimistic scenario. In the optimistic scenario, big tech really sets out to 'do no evil' and brings its immense resources to help improve the health of the rural poor and expects nothing back as a part of their philanthropy. It benefits by raising overall wealth and well-being, which creates more customers. In the more pessimistic scenario, the digital health tools that are used to support these communities improve their health are also used for much more targeted marketing and nudging these communities into consumption they don't really need and, in the worst case, these communities are overall worse off. We will see what happens, but probably a 'middle of the road' reality is most likely.

How do you think health care will change in the wake of the pandemic? I think many digital health technologies and applications had already been ready, from a technological maturity point of view. However, with COVID-19, we have seen overnight widespread acceptance. For example, seniors were the group that were often the most resistant to embracing digital health technologies, but they realised they were at the highest risk for COVID-19. They therefore did not want to come into the clinics, but now, finally, we had alignment of interests. Overall, I would say that COVID-19 has been catalytic, as these changes eventually would have occurred anyway.

We see technologies being implemented in entirely different ways across the globe, in some cases even the same technology. What do you think accounts for this difference?

Like Alfred Nobel's invention of dynamite, ultimately, technology is just technology, and how we use it will depend less on the technology itself and more on us. The answers will really be driven by pivotal events like the US presidential elections and the Sino-American geo-political contestation. I think these are far more important issues than any technology. I am very bullish about the technologies and their potential to benefit humankind, but much more sanguine about how the politics will play out.

How do we incentivise individuals in the East and the West to share more data?

In the East, citizens by and large have not asked the somewhat awkward questions like: "Hey, do the data not belong to me? Why can't I access them when I want or share them with whoever I want?" In many health systems here in Asia, one's health data belongs to the health system. You could not go to a hospital and say, you cannot use my data to monetise whatever, because it is the hospitals that own the data.

If you would have to imagine a dream scenario for healthcare in 2030, what would it look like?

I would go back to the World Health Organization and World Bank report from three years ago, which had two key highlights: Firstly, half the world still lacks access to essential health services, and secondly, a hundred million households are essentially pushed into bankruptcy due to medical reasons. So, a 2030 dream would be that these numbers dramatically diminish and that most or all the world, digitally or otherwise, have access to decent essential healthcare services, and that these are delivered in an affordable way.

... and towards 2040?

I am ironically a bit more pessimistic about 2040 because biomedical research is moving into ageing and trying to find the Holy Grail of immortality or extreme longevity. I suspect that in about 10 to 15 years or less, these technologies will become possible. But like most technologies. they will initially only be accessible to the wealthy. In a dystopian scenario, the rich and elite might decide they really do not want so many 'not so clever', 'not so productive' people on this planet who live to a hundred years or more. They might then try to withhold the technologies from these people who are 'less deserving' than they are.

If these technologies do become democratised, I think insurance and pension systems as we know them today will be completely turned upside down. The optimistic scenario is that society adapts successfully to this extreme longevity and we use the additional years meaningfully. The pessimistic one is where we fight with each other for constrained resources or we drive the planet into climate catastrophe even faster than we otherwise would have.

We share data

PHOTO ARTUR ŁUCZKA



n 2017, The Economist declared data, as opposed to oil, the world's most valuable resource of the 21st century⁹⁹, and with good reason. Data, including health data are being produced at an unparalleled pace. In 2018 it was 2.5 quintillion bytes per day vs. 95,192,000 barrels of oil per day globally¹⁰⁰.We only use 3% of this data. Health data range far and wide, from genomic and clinical imaging data to social media usage and data from personal wearables. The amount and complexity of these different data types is driving a paradigm shift within health systems that focuses on the collection, storage, combination, and analysis of data. This offers opportunities to better understand the complex interplay between biology, behaviour, and health, which provides the public system with ways to optimise the quality of life and provide better care and wellbeing and the private sector with opportunities to enter and innovate within the health system.

TYPES OF DATA

Health data can be broken down into traditional health related data, such as those found in medical records and biobanks and modern forms of data like real-world data (RWD) which includes behavioural and social media data. RWD can come from a number of sources, for example: claims and billing activities, product and disease registries, patient-generated data including in home-use settings, and data gathered from other sources that can inform on health status, such as mobile devices. Behavioural data includes data from personal devices like mobile phones, computers, loyalty cards etc., acting like a personal digital footprint. Some of these data are of course health-related such as eating habits, physical activity, resting heart rate, and smoking habits.

Data can roughly be divided into structured and unstructured health-related data. Structured data can be characterised by information that is collected, organised, and provided such that it is immediately machine-readable. This may be clinical information in health records and sequencing data from biobanks. Unstructured data are not immediately machine-readable and must be reorganised, cleaned, filtered, or undergo intensive analysis to be broadly useful. Examples of unstructured data may be social media posts, information about a patient's movements, exercise routines, or consumption behaviour. While the broad cate-gories of structured and unstructured is by no means strict or final. There are many examples of data that could arguably be placed in either category or span the division between them, such as RWD. It depends on how the data are collected and used. For example, if RWD on physical activity are collected by a wearable fitness device like Fitbit, they may be considered structured. However, if information is provided to a healthcare professional in the form of a written or spoken narrative by an individual, it could be considered unstructured. As new kinds of data continue to emerge, these categories may be increasingly challenged.

Collecting and combining these different data types helps provide a more holistic picture of an individual's health. While it is crucial that clinical data is recorded and analysed in the most optimal way, it is also necessary to invest in collecting the modern types of data and, not least, ensuring interoperability, allowing different data systems to communicate.

INTEROPERABILITY

Interoperability of data is key. There is a wide variety of data, collected in very different forms and formats and we can benefit much if there is interopeabily between systems and data. Consider genomics, where nearly 250 million genomes are currently available. While genomic data are relatively well structured, much of it is siloed by disease, institution, and country. They are also often generated with different methodologies, analysed by non-standardised software, and stored in incompatible file formats. Consequently, only a small percentage of genomic data is broadly available and applicable.

Interoperability can be achieved by using standards, where data entries are formalised in a way that provides consistent meaning to data shared among different information systems.¹⁰¹ To promote widespread usage and uptake, standards should be transparent, open, globally applicable, maintained with an ongoing process for testing and revision, and sustainable. It is also important to minimise the number of standards by strongly supporting the use of available global data standards or the development of new standards in fields where none are available to ensure early alignment. Therefore, international standards and guidelines should be established, and exchange of interoperable data across borders should be made possible. This is already underway in several collaborations such as Health Level 7 International (HL7), International Council for Harmonisation, International Consortium for Health Outcomes, International Organisation for Standardisation, Clinical Data Interchange Standards, Digital Imaging and Communications in Medicine, Genomic Standards Consortium, Snomed Clinical Terms, and Integrating in Healthcare Enterprise. Nevertheless, it is also important to develop standards for more complex and dynamic data such as proteomics and modern data outside the realm of the clinic (e.g. RWD).

An example of a data interoperability system based on standards is found in the Estonian public sector, which utilises the 'Xroad' concept. The key value behind X-road is interoperability, which enables the integration of data from different public and private organisations and information systems. All outgoing data from X-road is digitally signed and encrypted, and all incoming data is authenticated and logged. Citizens are never asked to fill out the same information twice due to all their data being available to the relevant authorities. This works by allowing approved databases to request and share data automatically. The functionality of X-road is estimated to save Estonia 800 man-years of labour every year. The success from X-road has spurred development and implementation in Finland, Faroe Islands, Azerbaijan, and Namibia.

An issue is to determine which stakeholder should be responsible for implementing interoperability; ensuring that those investing in interoperability are rewarded in some form. How this can be achieved is unclear. As Charles Jaffe, CEO of HL7, puts it: "Fundamentally, I consider the biggest impediment the business case. Why would I do it? You can't expect the for-profit vendors to connect everyone on their own dime ... why would I want to share data with my competitor when I've been trying to keep data from him for about 10 years?"¹⁰²

DATA SECURITY

As healthcare becomes increasingly digitalised and more data becomes available, data storage, security, safety and privacy discussions become more important. Data privacy will likely be viewed as a human right, which means that the system must ensure strong privacy. In return for this, individuals may place trust in the system and allow wider use of their data. This trust could be attained through strict security, transparency, and traceability measures and by applying the concept of dynamic consent. Dynamic consent is a concept that has been developed to support patients and research volunteers to have greater control over how their data and samples are being used in research, and increasingly in clinical care. It is designed to support an informed consent process that allows patients to determine their level of engagement and have access to an electronic record of their consent decisions that can be reviewed and updated over time.¹⁰³

There should be transparency and traceability regarding the flow of data and purpose of use, which could be obtained through logging systems. Both the individual and the end user, e.g. a scientist, will need to be ensured that the health data is secure and can be validated without a centralised actor. Data should therefore be secured from breaches in privacy through a decentralised ledger technology, e.g. blockchain, which enables a form of institutionalised trust.

HOW CAN DATA BE USED?

All this generated data must be used in order to be of value to society and it's citizens. Data must not only be collected, but also analysed, interpreted and used. The DIKW hierarchy was developed by Russel Ackoff, more than 30 years ago, to describe the functional relationship between data, information, knowledge and wisdom. The figure on page 45 shows the data-to-informationto-knowledge-to-wisdom transformation.

HOW DATA BENEFITS SOCIETY

The sheer amount of information drawn from data has already shown to be of benefit for both society and individuals. Big data can transform society for the better and enable organisations to make more informed decisions. However, entities dealing with big data should focus on the value that organisations, businesses, and governments can extract from the data rather than collecting just for the sake of collecting or for commercial purposes that don't align with what is beneficial to society.

Businesses can create new and innovative products catering to the highly personalised needs of consumers. They can interpret and use data to create more complete profiles of individuals and sort them into narrow segments of preference, likes, and dislikes. Netflix, for example, is using big data to understand their customers and target them with personalised suggestions based on their viewing history. What is stopping us from doing the same with health?

Governments can take the leap and establish smart cities that integrate environmental data and citizen-generated data into their ecosystems. In addition to smart cities, big data enable the foundation of smarter government systems that seek to lessen the red tape citizens are faced with when they need to interact with the authorities.¹⁰⁴ In terms of healthcare, the system could use combined data on the individual's lifestyle, history, and genetics to obtain a more holistic picture that can aid doctors in providing the most effective care. Biomedical data concerning genomics can be used in precision medicine where data from, for example, pharmacogenomics will lead to individualised treatment. Moreover, people could be empowered to play a much more active role in their health and wellbeing with information tailored to their specific needs.

HOW DATA BENEFITS THE INDIVIDUAL

Individuals also benefit from collecting and sharing data with others. The more health-relevant data the public health system have on an individual, the better they can tailor options for them. In the private sector, individuals are incentivised to share their data to get more personalised offers to improve their health through nudging. Education in health is key, and health data play an important role in this education. Health literacy in the future comes from turning personal health data into knowledge that help individuals understand how their behaviour affects their health in the long term and how to act on this knowledge.

If we want a healthcare system where prevention plays as large a role as treatment does today, people must actively keep themselves healthy, and real-time biological and behavioural data will enable individuals to proactively engage in preventive health and follow their progress or discover barriers they might face. Digital technologies like mhealth and telemedicine, combined with everincreasing amounts of real-time, real-world data, make it possible to draw the point of care closer to the individual, even allowing individuals to become their own point of care. Individuals could become less dependent on the clinical healthcare system while also increasing their health literacy, allowing informed decisions and conscious interactions regarding their health. The data obtained from the individual through e.g. wearable technology would also be analysed and further qualified by the healthcare system, contributing to population health datasets and research, which in turn provide evidence-based care and precision public health.

All verified clinical data on an individual can be collected and stored in a medical 'digital twin', which essentially is a digital replica that can be analysed independently of its real-world counterpart in order to make informed decisions. Drugs can be tested for effectiveness on a patient's digital twin instead of the patient itself, not unlike in silico testing and organ-on-a-chip. This will inevitably save time and money and enable more personalised medicine. A digital twin can be expanded to become a 'digital triplet' by adding real-time data and information from wearables and combining these with behavioural data. Unlike a digital twin, the digital triplet also allows for testing of behavioural changes on health outcomes. The digital triplet gives individuals an experimental sandbox for how their health will develop depending on the choices they make, testing how any hypothetical behaviour change could affect their health and what would be most effective in relation to their own health. In the following pages, we present the Humanome, which is the Copenhagen Institute for Futures Studies' model for a medical digital triplet.

CONCEPTUAL RELATIONS IN DIKW



The

Humanome

The Humanome model is a personal health profile and data repository. It is based on data that influence personal health parameters from both public and private-sector sources. The individual is placed at the centre, surrounded by a virtual assistant. Four circles represent categories, with some examples of data included, that to varying degrees affects health status. The top circle is personal behaviour, which includes data such as social media usage, physical activity, and dietary habits. The right category is *biology*, which covers data points like genomics, other -omics, and classical biomarkers. The bottom category is societal factors which e.g. includes data points like employment, education, and demographics. The left circle is environmental factors, covering data points such as climate, pollution, and noise. Data controls and contracts feature on the outermost circles, as all data flows in the Humanome need to comply with specific controls. They cover aspects such as interoperability, security, and safety of data, as well as transparency, traceability, and accountability for the flow and handling of data. Data contracts cover consent, donation, and sharing of data, as well as secondary use, anti-lock-in systems, and logging of data. These safety measures in data management are crucial and enable trust between individuals and institutions across sectors.

The Humanome is not meant to be a complete list of existing types of data. It is meant to serve as an inspiration for what types of data are already available, from the human body and its surroundings. Furthermore, the individual is not expected to collect, analyse, and interpret all the data in the Humanome on their own. The clinical and non-clinical sources of individual data could be interpreted and presented by a virtual assistant in the shape of artificial intelligence or a digital interface.

The Humanome is made up of two parts, 'Human' and the suffix '-ome'. The suffix '-ome' is related to the totality of a subject and here the subject is the health of a human.



END OF SHIFT COVID-19





OLIVIA GIORGI infermiere intensiva

San Salvatore Hospital



FEDERICO NERI infermiere anestesista

San Salvatore Hospital



VINCENZO SICILIANO infermiere terapia intensiva

San Salvatore Hospital



FRANCESCA PALUMBO infermiera terapia intensiva

San Salvatore Hospital



FEDERICO PAOLIN medico anestesista

San Salvatore Hospital



SILVIA LIGI medico anestesista

San Salvatore Hospital

Dynamic consent and ethics in health

We sat down with Harriet Teare, the previous Deputy Director at The Centre for Health, Law and Emerging Technologies (HeLEX) at the University of Oxford. HeLEX is a multidisciplinary centre with a focus on academic law and during her tenure, there was an enhanced focus on working with ethics regulation and governance and how these elements support medical research in the form of dynamic consent.

What interested you the most in the field of ethics?

I spent a long time thinking about the informed consent process. Informed consent is a key part of medical research where participants can be informed in their agency to take part in research. But as the scope of research changes, so does the notion of informed consent.

Dynamic consent was a project that my team in Oxford have worked on for 10-12 years. It is an approach to support informed consent and was originally coined in response to biobanking. Biobanking is where collections of human biological samples have been brought together for future research. The biobanks recruit several hundred people and ask for their samples, and they will say, we want to do research and researchers will come to us in the future to access your samples for research. From an informed consent point of view, this raised a number of questions about whether or not people could be truly informed of what was going to happen with their data and samples, as the research they gave their samples to had not actually been defined yet. This is what



the dynamic consent team was trying to tackle, and the solution developed was to move the consent from being a single interaction when the samples were taken to become a conversation with participants over time, so that they could come back and review what they'd agreed to and receive updates on what was happening with their data and samples. In practical terms, it is a digital interface or patient portal where you would be able to access the consent decisions that you had made, review whether they still stand, and change them if your circumstances have changed. I did quite a lot of work talking to patients, and they really liked this approach because they felt they could change their mind; they were more trusting. Views on what dynamic consent should cover shifted because originally it had really been related to the consent question, but it became much more an approach for consent and engagement. On that note, I think it is potentially a tool that could help manage decision-making in all sorts of areas, not just medical research.

What would you say is the biggest ethical issue we need to overcome to share health data?

When we talk about ethics, particularly in medical research, people refer to four pillars: autonomy, justice, beneficence, and nonmaleficence. Autonomy for me is especially interesting, as a lot of the conversations we have around data are around individuals being able to make decisions about how their data are being used. That is a real focus on autonomy, as we are essentially giving people responsibility by empowering them to make those decisions. It is a significant conversation around the implications of data, digital health, online data sharing, etc., and whether or not data sharing is threatened if people can't really understand the extent to which data about them are collected and how they are used. How, then, does that influence meaningful decision making as well as assert their autonomy? Another super-interesting question is a philosophical one, about exerting your autonomy to not wanting to know things as well as wanting to know. I spent a lot of time thinking about the area of genomics research, because what you find out about a person when sequencing their genomes is sometimes outside the original scope to the research. There is a huge disagreement in the ethical community about handing back versus not handing back information. Some people think it should be up to the individual to decide what to do with that information, while lots of other people think you should not hand information back because it was not the purpose of the research. I am not saying one is right and one is wrong. What I do think is important is that data practices change.

How do we enable the use and reuse of data for the public benefit rather than only for commercial purposes, such as the business model of 23andMe?

There is a lot of discussion around the social contract, since researchers need the data to do the research to understand how to deliver healthcare better. We also need the data to do the research to support people becoming healthier. Healthcare delivery increasingly relies on large amounts of data, so we need people to be involved in this process and encourage them to make decisions about their lives. On that note, I think there is an awful lot that can be learned from the likes of 23andMe, whether or not you agree with their business model. They are engaging people with quite complex data that are relevant to their own individual circumstance, on an interactive platform that allows people to look at data in quite an interesting way, and they've clearly thought about it quite carefully because it's consumer-driven. This is an area that public groups could look at and learn from because there is a huge opportunity with tech and digital tools to present information in different ways to improve health literacy.

To summarise, there are two things that we can think about. One is how you display the information so that it is accessible and useful, and the FAIR (ed.: Findable, Accessible, Interoperable, Reusable) data principles are all part of that process. The second is how you open a meaningful conversation with people about the social contract if we want to improve our health system. How do we get people to be supportive of handing their data over to do that? Without lots of people sharing their data, we are not going to make progress

How do you see the difference in ethics in the monitoring and application of data between the East and the West?

I have done some work in Japan and Australia, and one of the interesting things was again this question of autonomy. In the West, we have a very strong sense of individuality; i.e., individuals making decisions for themselves, and in other cultures, there's much more focus on the group, whether the family group, community, or tribe. Making decisions as a group rather than as an individual is a much more immediate thing, and I think that is particularly important. As an example, genomics where the data that you are potentially sharing is not just relevant for you. There are other people for whom it might have implications. So, if I get sequenced and I receive that information, I am receiving information that is probably important for my sisters as well.

How can we strike the balance between confidentiality and duty to inform?

The duty of care and the duty of confidentiality are very well described within the law, particularly in the UK. In other legal systems that are similar, there are cases beginning to arise around how genetic information is being used and where people feel they should have been told and were not. At the moment, there are lots of policies in place to encourage people to raise things with their family members if it is relevant to their health.

As a specific example from my work, I have been in a project that had nothing to do with cancer. where the researchers had a good indication that the research participant had leukaemia. So, they found something that was actionable and hugely important for this person's health, and they could not feed it back. This is not my area of expertise, but it may well be that there are increasing numbers of cases where that happens; where we have individuals who are internally conflicted ethically about whether to respect confidentiality or provide information to people to whom it is super important. It is something that I think will progress and that we will need to keep thinking about quite carefully.

WHAT IS IN STORE

PHOTO ALEXANDER POPOV

for high, medium, and low maturity health systems?

In this article, we examine the potential for the future of health systems across the world, categorised as high, medium, and lowmaturity health systems today. The classification approximates how well health systems perform in terms of disease burden, mortality, providing efficient care, and hospital beds while also considering spending on health and other factors. Although this article takes its departure in how the health systems are performing in 2020, we aim to explore how they could look in the future, and hence we focus on the potential within the systems rather than looking at what they can and cannot do today. Levels of maturity are dynamic and so is the road to high maturity, and low-maturity systems today could take a different road to reach high maturity by using or inventing solutions that high-maturity health systems didn't have in their early stages.

HIGH-MATURITY HEALTH SYSTEMS – NEW SYSTEMS BIOLOGY

Today, countries that are better off economically have already made the epidemiological transition from communicable diseases (CDs) to non-communicable diseases (NCDs) due to advanced medical technologies and the widespread basic infrastructure required for the minimisation of communicable diseases. On the flip side, advanced economies can also afford conveniences that lead to a rise in NCDs, due to issues like sedentary lifestyles, unhealthy foods, and overconsumption. Health systems in this classification include countries such as South Korea, Canada, Australia, and most European countries.

Although basic infrastructure is present in high-maturity health systems, the coronavirus pandemic clearly highlighted that it might not be sufficient in case of a crisis as large as this one. Nevertheless, these systems have focused (and will likely continue to focus) on developing and implementing better medical care for non-communicable diseases, which are the most prevalent diseases there.

High-maturity systems invest most into health in the form of clinical research for improving cancer treatment, cardiovascular diseases treatment, and treatment of other non-communicable diseases. These innovations are usually very costly early in the development process and slowly decline in price until they become attainable for the general population. In terms of value for money, the way governments and companies in high-maturity systems have been investing is generally not efficient. For example, in the United States, a pioneer of high-maturity systems, investments in medical care are vastly greater than investments into other determinants of health, such as behaviour. In the US, the most important determinant of health is behaviour at 38%, with socioeconomic determinants coming in second at 23% and biology coming in third at 21%. Medical care, on the other hand, accounts for only 11% of the health impact, but spending on medical care is 222 times higher than spending on biology. See visualisation on page 61 that builds the determinants of health together with the spending on the specific areas in the US. The black bars show spending while the parts of the circle highlight percentages of determinants of health.

High-maturity systems will likely diversify and increase the spending on other determinants of health, such as biology, e.g. genomics as well as the other omics. Development of these medical innovations is expensive and requires that research and laboratory infrastructures are in place, which is why high-maturity systems have such a great opportunity to capitalise. A deeper understanding of biology will also inevitably lead to better medical care and in turn to a reduction in the burden of non-communicable disease. Wearable technology and real-time data can help prevent diseases while robots and AI can reduce labour expenses in healthcare and relieve qualified labour of routine tasks.

A good example of what kind of infrastructure high-maturity systems already have built up is the European 1+ Million Genomes Initiative; a collaboration aiming to link access to future genomic databases across the European Union.¹⁰⁵ This would not be possible without the already existing laboratories sequencing genomes, nor without the data infrastructure to support sharing across borders. Another example of what high maturity systems can accomplish is breaking down barriers to sharing data across borders. This is mainly a regulatory issue that, if not solved, will significantly slow down the progress towards better healthcare. A good example is The Nordic Commons, a report written by Nordforsk that highlights how to overcome the main challenges of sharing data across borders in the Nordics.¹⁰⁶ The identified challenges were technical, e.g. how a federated cloud could look; legislative, e.g. what needs to be done to not stifle innovation; and collaborative, e.g. ways of working together.

MEDIUM-MATURITY HEALTH SYSTEMS - TAKING ADVANTAGE OF BEHAVIOUR

For medium maturity-systems, the determinants of health are similar, as is the ratio of spending on different categories, while the overall per-capita spending is lower. As these systems do not necessarily have developed research and development infrastructures, there is a great opportunity in developing solutions for the other determinants of health, such as behaviour. Behaviour accounts for roughly 36% of the health status globally, and solutions do not necessarily require expensive infrastructure. A great example of this is mHealth, which was taking less mature systems in parts of Africa by storm even before COVID-19. Solutions like this will bring the medium maturity systems to higher levels of maturity, leapfrogging the challenges faced by other more advanced systems that have sunk costs in infrastructure. Therefore, leapfrogging as a concept is crucial for these countries to apply. Leapfrogging is defined by the World Economic Forum initiative Health Systems Leapfrogging in Emerging Economies as "using new technology, operating model, or pattern of behaviour to accelerate the development of a system by helping it skip over development stages that had previously been unavoidable".¹⁰⁷ Medium-maturity systems with the highest potential include China and India, as they have already shown the capacity to leapfrog and will most likely continue to do so.

An even more lucrative option is to focus on the behavioural determinants of health. Biology and medicinal sciences tell us *why* people fall ill, but not necessarily how to prevent it. For that, we need additional disciplines such as political science, economics, engineering, and other sciences. This is a field where the highmaturity systems have not paved the road yet, and there is still a lot to explore and experiment with. Behaviour is one of the most important determinants of health but is not receiving enough funding, given the potential it has in preventing illness down the line. Although global awareness of the impact of people's lifestyles is steadily increasing with new knowledge, governments and businesses are reluctant to invest heavily in solutions that would e.g. incentivise individuals to eat healthier. Behaviour is very difficult to study in a strictly controlled environment, which makes the return on investment difficult to quantify. However, with the advent of tracking wearables and other health devices, researchers have a vast amount of data to study and base conclusions upon.

A key advantage for medium-maturity systems is that they have not necessarily built expensive infrastructures that are incredibly difficult to reform. Additionally, while becoming market leaders in e.g. biotechnology is possible and important, unleashing the power of behavioural change has less competition globally due to its intangible nature. Therefore, medium-maturity systems can avoid the dependency of high-maturity systems on expensive infrastructures by investing in prevention through behavioural change and implementing policies for incentivising healthy behaviour. Health in all policies could be the mantra; after all, what determines our health the most is not the state of medical care but rather how we live our lives.

LOW-MATURITY HEALTH SYSTEMS - SOCIOECONOMIC FACTORS

Low-maturity health systems in 2020 have vastly different issues that their more advanced counterparts, which is reflected in their determinants of health. Health systems included under this classification are mainly situated in Central Africa. In these systems, many people's health are suffering because of a lack of social protection, employment, education, and housing, coupled with inadequate infrastructure and health systems. Behaviour has a relatively large effect on populations in high and medium-maturity systems and while it is still significant in low-maturity health systems, it is not the highest determinant. Socioeconomic factors take centre stage simply because of the lack of appropriate infrastructures for health literacy as well as for practising basic hygiene. In other words, the issue of health is much larger and more systemic than what can be strictly attributed to the health systems as such.

While this is the situation today, there is hope for the future, as these systems have made great strides in overall development and the reduction of communicable diseases. The fact that health technology is not the most important aspect of a health system is seen most clearly in low maturity systems where low-tech solutions have much larger impact than solutions that cannot be implemented due to lacking infrastructure. A way forward is to implement policies to lift people out of poverty and create social safety nets that are robust enough to handle the increasing burden of disease. In parallel to laying down the basic infrastructure to reduce the burden of disease, expansion of the health systems' capacities is required. Many of the countries in the low-maturity classification have shown the capability to leapfrog over challenges of the more advanced countries, just as the medium-maturity systems in India and China did.

DETERMINANTS OF HEALTH AND SPENDING IN THE UNITED STATES



The above visualisation builds the determinants of health together with the spending on the specific areas in the US. The black bars show spending while the parts of the circle highlight percentages of determinants of health.





NEW PLAYERS IN HEALTH QUOTES

"We're in this really great position that we can do what we've always done, which is look at it as the user looks at it. We can ask ourselves, how can we improve the health of the user, not worrying about if we can convince the federal government to give us a reimbursement or not. This is an area where Apple can make serious contributions over time."

Tim Cook

CEO, APPLE, (2018)¹⁰⁸

"One example is the current debate in the US about healthcare. Right now, there are two options: provide health insurance coverage to more people at higher cost, or provide less coverage at lower cost. But over a 20 year period, by helping scientists prevent and cure more diseases, our hope is to create a third option: provide everyone with great healthcare for less cost."

Mark Zuckerberg

FOUNDER OF FACEBOOK (2017)¹⁰⁹

"With recent advances at the intersection of science and technology, we have the opportunity to characterize human health with unprecedented depth and precision. The Project Baseline study is the first step on our journey to comprehensively map human health... We hope to create a dataset, tools and technologies that benefit the research ecosystem and humankind more broadly."

Jessica Mega

CHIEF MEDICAL OFFICER OF VERILY (2017)¹¹⁰

"My job for them is to figure out ways that we're going to drive better outcomes, better satisfaction with care and better cost efficiency with new models that can be incubated for all. One source of waste is our very high administrative costs. There are a lot of middlemen in the system, and there have to be solutions that simplify that, take some of the middlemen out of the system."

Atul Gawande

FORMER CEO OF THE AMAZON-BERKSHIRE-JPMORGAN HEALTHCARE PARTNERSHIP (2018)¹¹¹ The idea is really to see what can be done from leveraging some of the very large ecosystems of start-ups and technology companies that are working with us in alignment with areas of unmet needs. So as an industry, we have the responsibility to go beyond competition when the mission is to solve the problem of the world [COVID19 red.].

Elena Bonfiglioli

REGIONAL BUSINESS LEADER HEALTH AND LIFE SCIENCES EMEA, MICROSOFT (2020)¹¹²

"If the internet was the appetizer, then AI is the main course..."

Robin Li

CHAIRMAN & CEO OF BAIDU (2018)¹¹³

"AI doctors... have immense advantages in comparison to my flesh-and-blood doctor. I can take my personal physician with me on my smartphone. [1t] has all the time in the world for me. It has almost no limitations on the amount of data it can access and process. It will know my entire medical history. It will be able to be familiar with all the different diseases in the world, and with all the newest, latest medical research. It will be able to offer treatment far, far better than any human doctor."

Yuval Noah Harari

PHILOSOPHER AND AUTHOR OF SAPIENS, HOMO DEUS AND 21 LESSONS FOR THE 21ST CENTURY (2016)¹¹⁴

"The medical diagnosis will become very, very good through AI, and then the doctor is more of a human connector. And then maybe just four years of college is enough. Maybe nurse practitioners can become doctors. Maybe there's more training about how to comfort and how to tease out from the patient, 'What are you really feeling?' So doctors can become this compassionate profession."

Kai-fu Lee

FORMER GOOGLE CHINA PRESIDENT AND AUTHOR OF AI SUPERPOWERS (2018)¹¹⁵



LININ

PHOTO DARIA SHEVTSOVA

With smartphones in pockets, citizens are connected to a global healthcare market – a market that is expanding at an accelerating pace as new, tech-savvy players enter to capitalise on the emerging changes in demand and opportunities. In this section, we take a closer look at how new actors on the health scene are creating consumer-centric solutions and services while filling the gaps of traditional healthcare providers with their global reach, innovation power, and fast prototyping. They are poised to shake up the established industry and pull billions in revenue from the established system through advantageous positions in the new, unbundled health economy, with profound implications for both new and traditional players in the field.

THE CITIZEN'S NEW ROLE AS A CONSUMER OF HEALTHCARE

Traditionally, a citizen's role in healthcare was primarily to contribute with descriptions of symptoms of disease, while the established system largely had a monopoly in knowledge and decision making. However, recent developments in health delivery are steadily transforming patients into consumers of healthcare services, as they navigate the global abundance of healthcare services from a rapidly growing number of providers. This newfound consumer role will change the nature of visiting the doctor through a largely unnoticed exchange of data and knowledge, already seen in today's emerging forms of connected wearables, digital therapeutics, and the medical internet of things. This will create the foundation for a different, largely virtual, and more convenient dialogue between citizen and health sector; a trend that will grow with the continuous proliferation and advancement of digital healthcare solutions.

These approaches enable an 'unbundling' of healthcare services that traditionally were centred around hospitals and general practitioners. Instead of directing all patients through one-size-fits-all processes at a hospital, diagnoses for minor symptoms can be handled virtually, keeping emergency rooms free for more urgent cases. Rather than having one provider, whether a hospital or a general practitioner, making all the decisions, a patient can choose between different providers for different services.

When citizens can monitor and collect data about themselves, the starting point for meeting the health sector is based on a much higher degree of knowledge, generated by the citizens themselves. Citizens will be given the opportunity to play a larger and more active role in their own health, treatments, and prevention of disease. As the established healthcare sector no longer has a monopoly on health knowledge and decision making, it must start to integrate the rapidly growing amounts of knowledge and data that citizens generate and bring to the table.¹¹⁶ If the established system ignores these new realities driven by citizen data, the private sector will not sit idly by, but introduce their own services (as is already happening), slowly making the traditional structures obsolete.

THE POWER OF KNOWING YOU BETTER

The world's leading tech companies have long considered healthcare an unexploited territory; but making a dent in a strongly regulated industry has not been easy. Medical professionals are reluctant to change ingrained procedures, and there are ethical issues about sensitive data monopolies and third-party usage. Even so, digitisation, personalisation, and data analysis are putting the established system and the life sciences under pressure, while tech companies are on the rise with a new view of how to deliver health and handle disease in a personal and convenient way. With strong capacities and a global reach, it is possible to store, transmit, and analyse the vast data sets in the cloud while expanding the widely applicable tools of the future, such as AI and machine learning, where governments often lag behind. These digital developments have already opened significant opportunities for Apple, Amazon, Facebook, Microsoft, and Google - and Tencent, Baidu, Huawei, and Alibaba, for that matter. Through already knowing citizens' identities, preferences, relationships, and interests better than the established healthcare system, the dominant players are monetising health-related-consumer data as a fundamental asset for the future. Just two companies, Google and Facebook, already know most of people's lives in detail from across their owned services (Google search, Google Maps, Gmail, You-Tube, Facebook, Instagram, WhatsApp, Messenger, etc.), and they are selling targeted advertising based on the unique knowledge of consumer receptiveness to marketing messages. By crossreferencing viewing habits and shopping behaviour, Amazon can compete as a gigantic retailer instantly in all verticals, and by tying consumers' identities and data to personal devices through design considerations, Apple can make it close to impossible to stop using their products and make upgrades and upsells self-evident.

BIG TECH'S LATEST MOVES INTO HEALTHCARE

Most tech players are advancing in the health space by playing to their strengths, where patient-centric visions prioritise consumers, while continuing to apply AI to everything from medical devices to lifestyle management solutions and building health data management in the cloud. Below, we look at some of the tech giants' latest moves into healthcare:

Facebook – in 2019, the social media giant launched a tool called 'Preventive Health', which uses a user's social determinants like age, gender, and education to provide preventative healthcare information, such as suggested check-ups, and connect them to service providers. Working with the American Cancer Society, the American College of Cardiology, the American Heart Association, and the Centre for Disease Control and Prevention, Facebook's new tool aims to synthesise preventive healthcare suggestions from professional and federal health organisations into simple, consumer-friendly reminders.¹¹⁷

Google – after the discontinuation in 2012 of Google Health, an attempt to create a repository of health records and data to connect doctors, hospitals, and pharmacies directly, the company has continued to expand its health efforts to enhance diagnostics and clinician's abilities to treat patients (which has caused some controversy in how data is collected and used). Its many ventures include the data-storage platform Google Cloud, the deep-learning tool Google Brain, the wearables application Google Fit, and the home automation brand Nest – all efforts to make health journeys seamless across the Google domains. The portfolio of Alpha-

bet, Googles parent company, houses several other health projects, such as Calico (anti-ageing) and Verily (life sciences research), and its venture capital wing Google Ventures has backed close to sixty health-related firms, including 23andMe and Doctor on Demand, and filed for hundreds of patents related to healthcare, while working on official partnerships with prominent providers such as Stanford Medicine, Cleveland Clinic, and Mayo Clinic.¹¹⁸

Amazon – the e-commerce behemoth is entering healthcare with its comprehensive infrastructure in logistics and computing and high consumer loyalty across the globe. It is easy to imagine how the 2018 acquisition of PillPack for nearly USD 1 billion will forge a path towards a gigantic online pharmacy, and in 2019, Amazon Care, a joint venture with JPMorgan Chase and Berkshire Hathaway, was announced to improve healthcare for the collective 1.2 million employees. The Amazon Care offering shapes healthcare services for its employees, carrying prescription drugs through its delivery network, and using its cloud computing arm to improve the efficiency at healthcare organisations. It includes virtual and in-person healthcare, telemedicine, chat, and remote video via an app, as well as follow-up visits and prescription-drug delivery directly to employees' home or office.¹¹⁹ With Amazon Care, the company raises the bar for employer healthcare in the future.

Apple – Apple perceives healthcare and wellness as an essential part of its universe of apps, services, and wearables. The strong brand has led to incredible loyal and direct connections with more than 700 million users, giving the company a distribution and size advantage for its app Apple Health, which monitors users through the day from pocket or wrist. With the release of the Apple Health Record in 2018 and the Apple Watch wearable device, it is evident that Apple hopes to build a healthcare platform open to integration, set to become a personal health record for its many users.¹²⁰

Microsoft - in May 2020, Microsoft announced that it will be launching a Cloud for Healthcare as its first effort in industryspecific cloud offerings. The Industry Clouds will bring together the tools in Microsoft services, such as Teams, Azure IoT, and chatbots, with features designed to address the needs of the healthcare industry. These include Microsoft's Booking app, a telemedicine initiative that enables patient engagement through virtual care journeys to alleviate overburdened physicians. Further, the Dynamics 365 Marketing and Customer Service tools will help create individualised care plans, proactive contact with patients, and remote monitoring via Microsoft's Azure IoT, which allows medical devices to exchange data in real-time; something that can help reduce readmission and associated costs through quickly escalated care in emergency situations. These new initiatives are being rolled out at a prime time for Microsoft, as the COVID19 pandemic urges the importance of seamless interoperability, and given that the trials are successful, they will probably outlive the viral outbreak.121

THE CHINESE LEAPFROG

Over the last decade, China has made significant advances in its healthcare market, which is forecast to reach USD 28.6 billion in 2026; a tenfold increase from 2016. The country has introduced large-scale reforms of its medical infrastructure and insurance systems while opening the market for healthcare, which has been positioned as an arena for foreign investment. China has made it clear that health technology is a strategically prioritised area, widely featured in the 'Healthy China 2030' strategy.

With objectives to improve access to as well as the quality and cost-effectiveness of China's healthcare services, Chinese tech giants like Alibaba, Baidu, Huawei, and Tencent have with large-scale investments paved the way for a tech-driven healthcare revolution from the East. China aims to be a world leader in AI-driven personalised medicine, and in November 2017, Baidu, Alibaba, and Tencent – collectively known as BAT – were named as the country's national AI champions.

Baidu – Baidu, known as China's largest search engine, aims to use blockchain ledger technology to promote the secure sharing and distribution of sensitive and medical data. Baidu hopes to tackle the inefficiencies associated with the current Chinese healthcare system. The blockchain solution aims to store patient's health records, including diagnoses, treatments, and prescriptions, on the company's own open-source platform XuperChain, with a twofold goal: to provide a one-stop-shop of data, including healthrelevant data, and to process insurance claims.¹²²

Alibaba – Alibaba Group, which has interests in e-commerce and payments solutions (Alipay), has launched a 24-hour medicine delivery service. Further, the company is supporting China's primary care system with its comprehensive reach in order to resolve regional resource inequality while facilitating online doctor consultations, as well as the application of AI in diagnostics and healthcare to make medical treatment more accessible, timely, and affordable through its cloud solution Alibaba Cloud.¹²³

Tencent – as of March 2018, Tencent-owned WeChat crossed the threshold of 1 billion users worldwide. More than 38,000 medical institutions worldwide have a WeChat account, and 60% of those institutions allow patients to book appointments online. Additionally, 2,000 hospitals accept payment by WeChat. These services allow Tencent to collect valuable consumer data that help train AI algorithms. Through a recent partnership with Babylon Health, WeChat users will have access to a virtual healthcare assistant. Pushing the envelope even further, Tencent has invested in iCarbonX, a company that aims to develop a digital representation of individuals (a 'digital twin', see page 44) to help perfect personalised medicine.¹²⁴

Huawei – a market leader in the rollout of the 5G network, Huawei is at the forefront of ICT solutions that serve the global healthcare industry. The company has launched a series of solutions, called "Smart Hospital", "Regional Healthcare", and "Remote Healthcare", with nearly 100 hospitals exploring different use cases of 5G + healthcare, such as remote group consultation, remote surgery, emergency rescue, and intra-hospital monitoring.

REDESIGNING THE MARKET AND REDEFINING THE ROLES

At the time of writing, technology companies are leveraging their participation in the world's largest health crisis to turbocharge the deployment of their health-relevant solutions. Apple and Google recently developed APIs that public health authorities can use to access data from smartphones through short-range Bluetooth tracks whenever infected individuals' smartphones came within a specified range of non-infected people. The apps developed by Apple and Google constitute a decentralised and voluntary approach to contact tracing, in contrast to the approach taken by the South Korean government where citizens are required to engage in contact tracing. This highlights an important debate about where the boundaries between individual freedom and mandatory data collection should be drawn in the name of public health in the future.

With its latest push into healthcare, Big Tech seems to have learned from both their own failures and those of the established systems, and along with what some medical experts describe as 'a new-found modesty' has come an effort to develop much greater expertise. As Eric Topol, author of the best seller Deep Medicine, commented in a 2020 *Financial Times interview*: "Each of these companies has chief medical officers, a big staff of physicians and clinicians. They realise it has to be different from what they have done in the past."¹²⁵

To provide preventive structures and precision services across the board of emerging health technologies, new players need to enter the health arena; an arena that is broader than our traditional health services, aiming at improving people's lifelong well-being and quality of life. One issue in realising the promise of personalised health is funding: Who are interested in and willing to invest in prevention and precision-health knowledge and services? This requires players who can approach the challenge in a long-term perspective, from cradle to grave, who can capture the need for a holistic whole-person approach while also nurturing hyper-specialisation, and who have an interest in individual quality of life and well-being as well as public health. Likely players on the global, regional, and local stages will be insurance companies and pension funds, who have a clear benefit in keeping their customers as healthy as possible. The counterincentive for these types of players is that they draw less benefit from customers once they stop working, and this is an issue that requires attention.

The 2020s will manifest the emergence of Big Tech in the healthcare sector, despite the initial scepticism as the interests of the healthcare system (long-term public benefits) and the interests of tech players (short-term profits) were at odds with one another. Over time, this distinction between public and private will blur because of changing priorities. Citizens and healthcare personnel will demand efficiency and results, irrespective of the governance structure. The overriding sentiment calls for prioritising health, both sick care and prevention. If the established healthcare system, which generally has been reactive in nature, aspires to become resilient enough to keep up with the entry over the coming decade of privately-owned players in the healthcare system, it will have to continually play catch-up with developments in the external environment. Though initially challenged, established key players in the healthcare system will have to recognise the potential in reorganising healthcare for the next era to see an increase in public-private partnerships and innovation targeted towards the healthcare sector.

A BRIEF OVERVIEW OF HEALTHCARE ECONOMICS

This article focuses on how health is funded, in what way providers of care are reimbursed today, and what healthcare economics could look like in the future. We present five main ways that healthcare is being funded today and five main ways that healthcare providers are being reimbursed for their services. Lastly, we present the future thinking about how healthcare could be financed and re-imbursed looking at concepts such as reimbursement based on patient-reported outcome measures and Value based healthcare.

Models of healthcare funding



UNIVERSAL GOVERNMENT-FUNDED HEALTH

In this system, the cost of healthcare for all residents of a country is covered by a single, government-funded public system, usually referred to as a *single-payer system*. While healthcare is paid for by the government, which may own its own hospitals and employ its own personnel, private actors may be contracted to provide care, and often, dentistry and medicine are only partly covered by the government. Competition in the healthcare market is low, with the government being the main provider. Unlike private healthcare, the goal is not to make a profit from healthcare, but rather to get the most healthcare possible out of the available budget. This typically makes it possible to keep costs relatively low. This model is commonly praised for giving everybody access to healthcare, regardless of wealth, thus ensuring a high level of public health. A common criticism is that waiting time for patients may be long because everyone is guaranteed healthcare and budgets often con-

strict both the amount and availability of healthcare professionals.

Examples: Australia, Denmark, South Africa, Saudi Arabia, and Brazil
UNIVERSAL PUBLIC INSURANCE

In this system, healthcare is paid by personal insurance, which is usually tied to employment; i.e., employees have health insurance paid by their employers. Most often, the government intervenes in the insurance market to ensure that specific groups of individuals are insured and protected against the risk of any health emergency that could otherwise lead to financial problems. A part of employee wages is withheld from the employee by the government, and the employer also contributes separately. In this form of system, individuals' claims are dependent on their contributions, meaning that people who are not legally employed or registered as unemployed may not have access to free healthcare.

Examples: Russia, Poland, Belgium, Qatar, China, Colombia, and Singapore

UNIVERSAL PRIVATE INSURANCE

In this system, individuals are obligated to purchase private insurance, and those who cannot afford it are subsidised by the government. This model features insurance based on managing competition in the private sector where pre-existing conditions are not grounds for exclusion from insurance. Additionally, insurers are not allowed to make a profit on basic insurance but can sell supplemental plans. This system attempts to account for the disadvantage offered by compulsory private insurance by subsidising it as well as having a minimum amount of coverage. Therefore, these countries' health systems are generally performing well both in terms of patient satisfaction and outcomes. In turn, people that can't afford supplemental plans only have access to basic healthcare insurance.

Examples: Israel, Switzerland, and the Netherlands

UNIVERSAL PUBLIC-PRIVATE INSURANCE SYSTEM

In this system, insurance is mandatory either through private vendors or the public system. It is similar to the above system, with the exception that most people receive care through a primary private insurance, while only those who are ineligible for private insurance are covered by the government. Those covered by the government usually have to go through long wait times due to the number of patients covered and there are also disparities in what private insurance plans cover, although they are generally considered good quality.

Examples: Argentina, Germany, Turkey, and Algeria

NON-UNIVERSAL INSURANCE SYSTEMS

In this system, individuals either have private health insurance or are eligible for subsidised healthcare from the government, or they are not insured at all. There is no universal coverage program, and some citizens only have access to healthcare on a pay-per-visit case. A common praise for such systems is that the overall cost is not as prohibitive as universal healthcare and wait times for specialist visits are generally shorter. A common criticism is that people who, for whatever reason, don't have health insurances can go bankrupt from having to pay for care in case of unexpected disease or injury, or may even be denied life-saving care.

Examples: United States, Ethiopia, Jordan, Kenya, India

How healthcare systems will be funded in the future is not necessarily clear. While some countries are making the transition to providing universal healthcare to their populations, it is uncertain which system will provide the best coverage and (just as importantly) quality for citizens.

REIMBURSEMENT MODELS

Another aspect of health economics is how the providers of care are reimbursed and incentivised to provide the best possible care to citizens at a reasonable cost. Health services are mostly financed in 'silos', where each provider is paid separately, making health collaborations difficult to facilitate. This is called unbundled payments. A disadvantage of this is that it can lead to fragmentation in the health system as well as generally worse health outcomes for patients because providers are incentivized to order more services than the individual needs for economic gain. In a bundled payment system, providers share one reimbursement for a range of services rather than each provider being paid separately. This encourages more collaboration among multiple providers to coordinate the delivery of services and reduce costs.

Today, there are five main models of health reimbursement:

FEE-FOR-SERVICE

This is the most traditional model, which is still prevalent among general practitioners and for outpatient services. although some governments are trying to shift away from it. Payment is after the fact, based on patient visits and what services were provided to the patient. This is the predominant form of unbundled payment system.

DIAGNOSIS-RELATED GROUPS

This model is also called payment per case, as rather than paying for specific services, payment is made based on a classification of patients into groups based on diagnoses and considering resource use. It is used most often globally in hospital inpatient cases.

CAPITATION

This is an alternative model to fee-for-service in some countries for general practitioner visits. It aims to simplify reimbursement of providers by providing a lump sum for each enrolled patient that covers a range of services. This means that providers get paid based on how many patients they have enrolled at their clinic, regardless of whether they seek care or not. The sum is determined by the average expected healthcare utilisation of the specific patient, based on e.g. age and health status.

GLOBAL BUDGET – BUNDLED PAYMENT

This model is the middle road between fee-for-service and capitation, as it is a lump-sum payment that covers a wide range of services but is not tied to volume provided. It is also known as bundled payment, as it encourages cutting costs to keep within the allocated budget and is therefore one of the models used for public hospitals in multiple countries.

PAY FOR PERFORMANCE

This model does not function on its own, but is rather an add-on payment that can be applied on top of any of the above. It pays providers after the fact based on performance shown, measured among others things by patient readmission rates, disease control, and patient health outcomes. This provides incentive for providers to ensure the best treatment over cutting corners or charging for unnecessary expenses.



In terms of the future of reimbursement, these traditional forms are often not sufficient to reach the desired goals of improved quality of care. Additionally, new care models focusing on prevention and improving coordination among service providers are difficult to reimburse.

Current reimbursement models cover payments for the work and expenses of health providers; they do not necessarily incentivise them to provide better care for patients. A new way of thinking is required on how healthcare should be reimbursed that focuses on both value and health outcomes for individuals. The exact meaning of value in care varies greatly based on subjective perceptions of what good care is as well as what a good outcome is. In the future, the value of care may be better defined by the individuals receiving care than relying solely on what the system evaluates. This is not to say that performance measures will be obsolete in the future; health systems will likely still heavily rely on them to know how to increase efficiency and improve quality.

Patient-reported outcome measures (PROMs) and patient-reported experience measures (PREMs) are already being utilised in clinical research, and there is an opportunity to use them in care settings as well. These measures are often highly subjective and mainly consist of filling out questionnaires that query how patients are feeling. In the future, the application of these measures, coupled with behavioural data gathered from a variety of different sources, can provide a more holistic picture of how individuals experience their care and the outcomes of their treatment. This real-world data helps both individuals as well as providers of care to far better measure the outcomes of specific interventions.

Value-based healthcare (VBHC), as described by professor Michael Porter, who introduced the term, has been a hot-button topic in the past decade and a half, and while some aspects of it are being implemented, it still has not reached the maturity to be adopted globally. There are some key considerations in this concept that will surely shape the future of healthcare delivery, such as the integrated units of care, measuring outcomes and costs, and moving to bundled payments. While VBHC provides a great starting point for discussion in reforming how health is delivered, it is important to take a step back and consider what outcome and value is to a citizen, to the healthcare system, and to society at large. In

other words, we need to ask the right questions and develop models based on that.





THE ORIGIN OF THE MODEL

s it has been highlighted here, there is a need for a new healthcare model that places colla-boration, personalisation, and most importantly, sustainability in the foreground as we move towards the next era in global health. Developing such a model presents a host of conceptual and practical challenges whose size increase in relation to the scope the model aims to cover. A model for the future of health that aims to be applicable on a global level requires not only that concepts are broad and generalisable enough to make sense in, at the very least, the majority of geopolitical contexts, but that they are also practically able to be realised in both resource-rich and -poor context. These conditions necessarily entail a degree of reductionism in how the health landscape looks and functions as well as how stakeholders within it interact. However, the purpose of such a model is not to illustrate how the world works, but rather what is needed to achieve a future vision for healthcare on a global level. With this in mind, The Copenhagen Institute for Futures Studies has developed the Sustainable Health Model that strives to lay out the principles that could inspire the collaborations that will drive the future of health across disciplines, backgrounds, and borders around the world.

THE ORIGIN FOR THE MODEL

The Sustainable Health Model rests on the Nordic Health 2030 programme, which is a pan-Nordic 2019 initiative facilitated by the Copenhagen Institute for Futures Studies. The goal was developing a coalition of public and private Nordic stakeholders with consensus on a direction for sustainable healthcare towards 2030 guided by the Nordic Council's agreement to make the Nordics the most integrated region in the world by 2030. Among the results are the Humanome (explored earlier in this report) and the Sustainable Health Model, which propose how more open flows of information and expertise can deliver better health outcomes for individuals, organisations, and societies in the Nordic region. While the model was developed specifically in and for the Nordic context, we here present a modified version that provides a firm basis for discussions and thinking about future developments in health on the global level.

At the most fundamental level, the Sustainable Health Model illustrates how better flows of data within and around healthcare systems can both ensure the long-term health and wellbeing of individuals as well as improve the performance of healthcare systems and population health. The model takes the form of a loop with three spaces (visualised on the next pages). On the left the Individual is displayed, representing individual health as well as aspects of how individuals interact with health systems and engage in health-related activities. This includes individuals' levels of digital and health literacy, how individuals access data and how their data is protected, how individuals share responsibility for their health with other actors and institutions in health systems, and how individuals' digital identities are designed and managed.

The right side of the model covers the health system. Here, the system is not defined in a narrow sense – it addresses 'concrete' aspects such as the health workforce, infrastructure, care models, and reimbursement, as well as less tangible aspects like sustainable incentive structures, approaches to achieving health equity, and policymaking approaches to health that view it as an investment rather than a cost.

Data is featured in the centre of the model, as it is proposed in this model as the key driver of future health ecosystems. The central data component covers how data can be securely stored and safely shared for use by individuals (both laypeople and professionals) and organisations, how data can drive collaboration between health ecosystem actors (anti-lock-in), consent models that give individuals more control over how their data is used as well as make data sharing easier, and the interoperability of data between institutions and across borders. Finally, the red arrows inside the loop illustrate how data, driven by the principles of the central data component, flows seamlessly between individuals and systems.

THE SUSTAINABLE HEALTH MODEL





THE PRINCIPLES OF THE SUSTAINABLE HEALTH MODEL

INDIVIDUAL

D A T A

Digital/ Health literacy

Individuals are supported and educated both through digital tools as well as by humans to get a holistic understanding of their health

Access to data

Every individual has access to all data that relates to them

Shared responsibility

Every individual has a shared responsibility for their own as well as their community's health

Safety & security

Data can be safely used by individuals to improve and maintain their health and wellbeing and is managed securely so it cannot be accessed and used by unwanted actors

Data practices

All data on an individual are transparent to show how they were created and traceable to show how they were used with accountability measures built in

Anti-data lock-in

Both technical and commercial data lock-in is prohibited by default

Protection of data

Every individual's data is protected against discrimination, future harm and abuse from criminals, the state, and organizations

Digital identity

Every individual has a personal identification number that is enclosed in their data and a digital identifier that enables them to use their data globally

Consent

New forms of consent need to balance both the individual as well as the societal benefit

SYSTEM

Incentive structures

Health systems will reimburse and incentivize based on outcomes for patients, society, and organizations

Health as an investment

Health spending is be seen as an investment in wellbeing and quality of life rather than a cost of providing care when needed

Equality and equity

Adequate care will be provided to all who need it but the system will also support keeping healthy individuals, healthy for as long as possible

Integrated care

Integrated health teams provide the most holistic service placing the individual in the centre

Interoperability

There needs to be some form of interoperability between separate sources and types of data

Future workforce

The health workforce is optimized to provide better care through humans supported by machines You, the reader, are now invited to dive into the Sustainable Health Model. Below you can consider which direction the future of healthcare should go. It is important to highlight that the developments might play out differently across the world. Hence, you should consider the whole spectrum. There is no universal direction or accepted answer, as each system is unique and what might be obvious in one region might be the opposite in another. Therefore, this interactive article takes the point of departure in what you, as an individual citizen, health professional or decision maker think about the future of healthcare. Imagine your ideal health system in the future and place a mark with a pen on where you see your system on the spectrum.



Now that you have had the opportunity to consider the way towards the futures of health, the question is how do we get there? What would be the steppingstones to reach that ideal health system? Please consider the above and let us know your thoughts.



Impacts on citizens, organisations & society

This report has taken a broad approach to the emerging paradigm shift in health around the world. A wide variety of topics has been explored, including present and future challenges to global health, deep changes in how we understand biology and employ technology, the rise of personalised health, how different regions of the globe may approach the next era in health, and new collaborations and players in the health landscape.

Many of the discussions around these topics point towards a diverse set of implications that the next era in global health has for three core groups: citizens, organisations, and society. In the following, we will review these implications and discuss the challenges, opportunities, and dilemmas these groups face as they draw nearer to the future of health.

CITIZENS

The emerging paradigm shift towards personalised health presents individuals with an unprecedented opportunity to take control over their health experiences and derive greater value and benefits from healthcare than ever before, while also introducing new questions about individual and social responsibility and privacy. An approach to health that places individuals in the centre of activities and that posits health as the maintenance and improvement of quality of life and wellbeing through prevention and treatment - rather than the absence and treatment of disease achieved through clinical interventions - promises to improve citizens' health outcomes as well as offer them a more active role in contributing to those outcomes. Moreover, more convenient and tailored health services that meet people where they are - in both the literal and figurative senses – and approach them as unique individuals that are the sum of their genetics, environment, behaviour, and social interactions indicate that healthcare will be more targeted, effective, and efficient for people and systems alike.

However, these benefits cannot be realised without several demands being placed on citizens. Many of the benefits of personalised health can only be realised through the development and, especially, the implementation of technologies and digital services. While this on one hand requires investment from governments, communities, and other payers and providers, it also requires that the individuals whose lives the many personalised health technologies and services are intended to improve possess adequate levels of technological and digital literacy to effectively make use of them. While this may be an insignificant issue in some areas, it may manifest as a major obstacle among less resourceful populations in both poor and rich countries. The consequences of such disparities for health outcomes can already be observed today: where levels of health literacy and access are low, poor outcomes tend to follow. As digital literacy and access to digital tools become more synonymous with health literacy and access, disparities in these areas need to be addressed to avoid a perpetuation of health inequities.

Data privacy and ownership also figure largely into how citizens may experience healthcare in the future. As individuals increasingly become the primary source of the data that will drive personalised health services, striking a balance between data privacy and usability will be key. Citizens, depending on the regulatory regime in which they find themselves, may be faced with a crucial decisions about how to manage their own data: Who should be able to access their data, and for what purposes and in what situations may the data be accessed? While the development of personalised health services and systems and, ultimately, the health and wellbeing of citizens themselves stand to benefit immensely from open flows of data, it may not always be viewed as being in an individuals' best interest, given the associated risks of data breaches and discrimination. Therefore, robust data security and legal protections are needed to ensure that data is managed properly and cannot be used to inflict harm on citizens.

Safety and reliability of data are also fundamental to a personalised health paradigm that genuinely works for citizens. To provide health services that are effective and safe for citizens to use in health-related decision making, data need to be representative, trustworthy, understandable, and applicable. Citizens also need to be empowered to access and use insights about their health with confidence and peace of mind.

ORGANISATIONS

The global shift towards personalised health presents organisations, whether private companies or public health institutions, with a range of new challenges and opportunities. One central question that will loom large is how to best compete or collaborate in a health landscape that is increasingly populated by a diverse set of players coming from outside the traditional boundaries of the health sector. The entrance of 'big tech' (represented by giants like Apple, Google, Amazon, and Microsoft in the West, and Tencent, Ping An, and Alibaba in the East) into the health sector creates unprecedented competition for healthcare providers in the area of personalisation. As personalised healthcare is in large part dependent on personal data, tech giants are already at a significant advantage, given their extensive access to users' personal, behavioural, and, increasingly, health data. However, 'traditional' health actors may also find opportunities to combine existing expertise with new forms of access. Myriad mutual benefits could be realised through collaborations between public and private actors that bring together different skillsets, disciplines, and perspectives from within and outside of the health sector. As a result, health ecosystems may emerge that address individuals' diverse needs and demands throughout the entirety of their health journeys.

However, developing new modes of collaboration may require new incentives and reimbursement models that encourage organisations to prioritise long-term thinking and eschew some forms of competition. This may take the form of a shift from fee-forservice reimbursement to fee-for-outcome reimbursement, which places an emphasis on the value individuals derive from their healthcare experiences. While some organisations are already attempting to reorient their operational and business models around value-based healthcare, making this transition may not be easy, especially for organisations that operate with thin margins. Moreover, while fee-for-outcome models may encourage organisations to work together to deliver the best possible value for individuals, the pressures they place on those that are slow or unable to adapt may result in collaboration becoming a codeword for mergers and acquisitions. How effectively organisations navigate competition and collaboration in the emerging health landscape may make the difference between a health ecosystem and a health oligopoly.

Another crucial aspect of collaboration between companies and organisations is the need for increased interoperability between the data they collect and hold. To identify patterns between different types of data from different sources and, ultimately, derive meaningful insights from them, datasets need to be interoperable. This requires the development and implementation of standards. Notably, interoperability should not be limited to technical standardisation, i.e., the usage of the same variables, methodologies, encoding, storage, etc., but also semantics, i.e., the same understanding of what terms and concepts mean to ensure that data is not only mechanically translatable, but also useful to people in all contexts. The need for widespread standardisation raises important questions about how the process might occur. Will standardisation be the result of widespread collaboration between healthcare organisations, top-down enforcement through regional or global institutions, bargaining among powerful actors, or a combination of these pathways? And what kinds of obstacles might the implementation of standards face depending on how they are devised?

The personalised health paradigm also presents companies and organisations with new responsibilities to individuals and society. As healthcare becomes more data-driven, companies and organisations (especially in the private sector) may face the challenge of taking on a new role defined by stewardship, as protection and validation of personal data will become fundamental activities. The need to ensure the security and veracity of data in the emerging healthcare landscape may also give rise to increased oversight and compliance requirements that could place a heavy burden on companies and organisations that lack the capacity to carry out more than their core activities.

SOCIETY

The next era in global health opens possibilities for unprecedented levels of collaboration across borders and disciplines, new forms of governance and regulation, more holistic approaches to healthcare, increased citizen empowerment, and equitable strategies for development of healthcare systems and services. However, achieving these goals requires significant institutional and societal changes. Most prominently, to reap the full benefits of personalised health, policymakers need to adapt to a more holistic view of health. This means that health, from an institutional perspective, cannot just be understood solely as the absence of disease, but rather as the sum of factors contributing to a person's quality of life and wellbeing. Making this change in perspective may require that health be featured in all aspects of policymaking and treated as a long-term investment rather than a cost. In addition, making the transition to personalised health requires that prevention, both within and outside of clinical settings, become a more significant aspect of healthcare activities.

In addition, governance and regulatory frameworks need to adapt to more flexible approaches to privacy, consent, and sharing of data. As the development, delivery, and innovation of healthcare becomes increasingly reliant on vast amounts of data, more efficient, effective, and secure ways of sharing data are needed. This may take the form of secondary use policies that allow for the sharing of data between different actors for specific purposes, dynamic consent frameworks that enable individuals to continuously determine how their data can be used and by whom (as opposed to rigid, one-time, blanket consent), and policies that prevent discrimination based on insights from personal health-related data while still enabling the use of real-world data and evidence for research and development in healthcare. Moreover, to truly thrust the world into the personalised health paradigm, governance and regulatory frameworks will have to be designed to look beyond national - and even regional - borders and break through disciplinary boundaries, as personalisation in health is dependent on worldwide sharing of data, expertise, and insights.

Realising the next era in global health also requires that societies implement existing technologies and identify ways of bringing a higher standard of healthcare to less resourceful jurisdictions without the establishment of cumbersome and costly physical infrastructure (i.e., 'leapfrogging'). As the COVID-19 pandemic illustrated, we have had a wealth of technologies at our disposal for many years that could revolutionise the development and delivery of healthcare and the protection of public health such as telemedicine and contact tracing, but it took a crisis of global proportions to get governments, companies, and individuals to implement and utilise them. Encouraging an 'implementation first' mindset may help accelerate the transition towards personalised health solutions. In less-developed jurisdictions, finding creative ways of both implementing existing technologies as well as bypassing the need for large capital investments may contribute substantially towards achieving greater health equity on a global level.

Perhaps most crucially, societies need to genuinely empower their citizens and communities to bring aspirations for the future of health to fruition. This means not only allocating resources to citizens according to their needs, but also helping them develop the capabilities to take the greatest possible advantage of the health services available to them as well as to take more responsibility for their own health and that of their communities. At the same time, empowerment also means providing communities with the necessary resources to ensure that they can support citizens. By equipping both citizens and communities with resources and skills, they will be able to more confidently navigate the emerging health landscape and work steadily toward securing a high quality of life and wellbeing for all.



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