THE GENOME e-VOLUTION

Ivan Đikić

BIG IDEAS

THE GENOME *e*-VOLUTION

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The genome e-volution

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BIG IDEAS

"We have made great progress, but we are still vulnerable and our common commitment to fight global health challenges is not yet strong enough. Despite our knowledge, despite new technologies, without concentrated and global efforts we are limited in our success. Today we see it clearly."

The sequencing of the human genome at the beginning of this millennium marked a new era in biomedicine. Nanotechnology and robotics have created innovative tools and powerful diagnostic techniques. Major therapeutic advances have enabled us to control HIV, and more tailor-made therapies are being implemented to treat cancer. Nonetheless huge challenges remain, not only in the field of cancer, but also with respect to neurodegenerative and other diseases.

At the same time, international travel and mobility, as well as globalised trade, are affecting our living conditions and promoting the spread of infectious diseases and new viruses, like the COVID-19 coronavirus, all over the world.

The Croatian physician and scientist Ivan Đikić analyses the challenges of contemporary medical research, the emerging threats, like pandemics, and the role played by health systems.

This is the twelfth essay in the *Big Ideas* series created by the European Investment Bank.

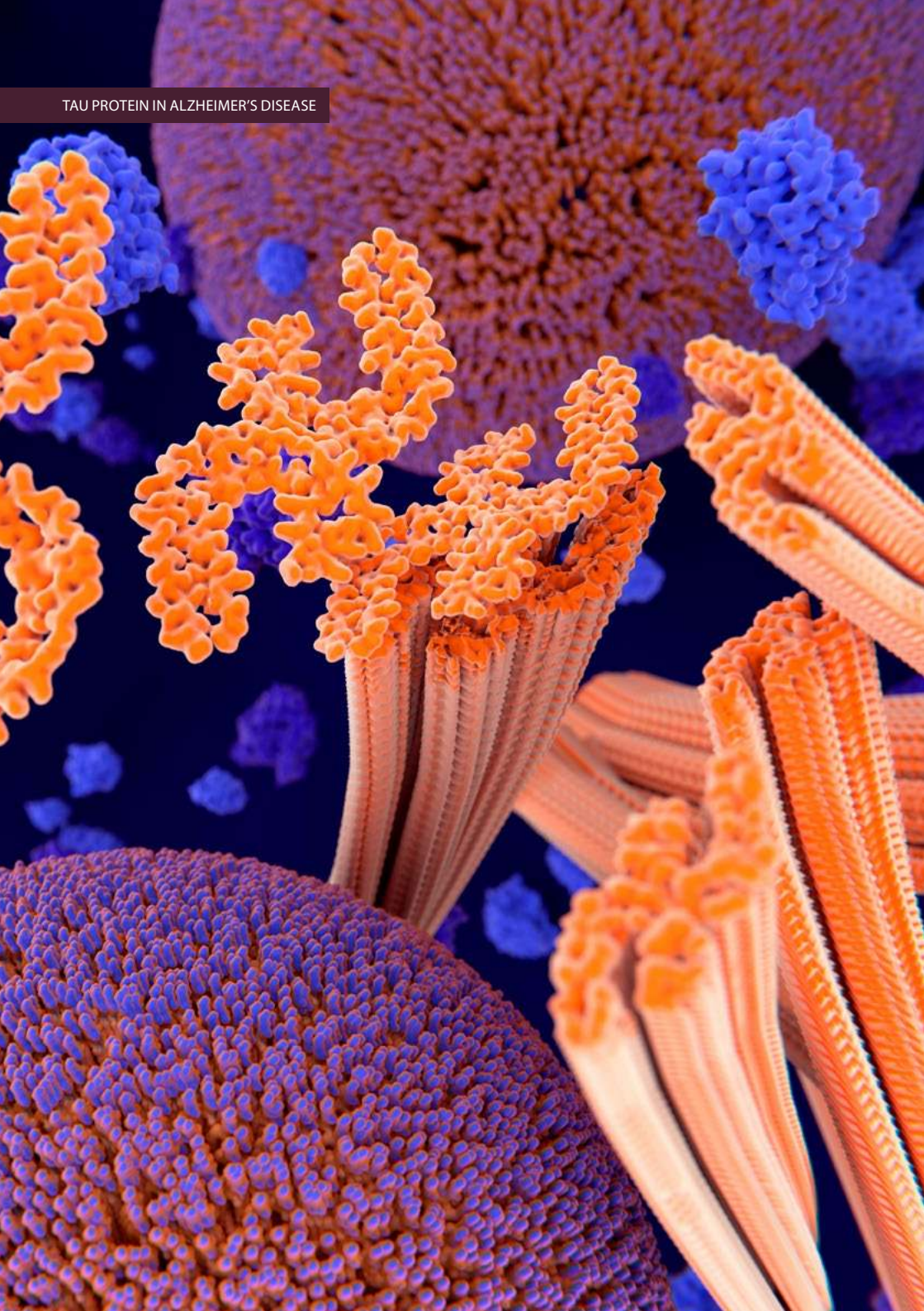
The EIB has invited international thought leaders to write about the most important issues of the day. These essays are a reminder that we need new thinking to protect the environment, promote equality and improve people's lives around the globe.


THE GENOME
e-VOLUTION

THE GENOME *e*-VOLUTION

The sequencing of the human genome at the beginning of this millennium marked a new era in biomedicine. Genome sequencing has become so fast and cheap that it can be routinely applied to individual patients leading to the identification of genetic variants that are on the one hand key drivers for disease development, and on the other hand the cause for differential response to therapies. Moreover, nanotechnology and robotics have created innovative therapeutic tools and powerful diagnostic techniques, such as the analysis of all human proteins (proteomics) and the processing of high-resolution imaging data for patient tissues that help diagnosis significantly by reliably detecting the first signs of disease. These technologies look at various aspects of disease changes over time and provide a more holistic picture of a patient's individual state. As a consequence of technological advances and the genome evolution in medicine, we can now provide better-tailored diagnostics, increased therapeutic efficacy and reduced side effects to an individual patient. Such "precision medicine" approaches promote advances in healthcare and prolong lifespan in the general population.

"The current pandemic caused by COVID-19 provides a bitter example of how vulnerable our systems are. In addition to unforeseeable threats from newly emerging viruses, changing demographics, especially with respect to urbanisation, an ageing population, societal developments, and untreatable neurodegenerative diseases all pose pressing concerns in Europe.


TAU PROTEIN IN ALZHEIMER'S DISEASE

Despite these achievements, significant health challenges remain, and the current pandemic caused by COVID-19 provides a bitter example of how vulnerable our systems are. In addition to unforeseeable threats from newly emerging viruses, changing demographics, especially with respect to urbanisation, an ageing population, societal developments, and untreatable neurodegenerative diseases all pose pressing concerns in Europe. Meanwhile, growing professional demands, chronic work stress, and the spread of new types of diseases through globalisation compound the situation. In view of these and other challenges, advancing health continues to be one of the most important challenges of modern societies.

The European Union and its Member States consider health to be among their top priorities. Through the EU Health Programme, Member States are trying to further reinforce health systems and enhance programmes aimed at educating citizens to form stronger and knowledge-based communities. This essay reflects on the scientific and technological advances that are providing new therapeutic opportunities for major human diseases and for securing health in Europe and around the globe.

LIFESTYLE AND CLIMATE CHANGE IS THREATENING OUR HEALTH

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Noncommunicable diseases (NCDs) such as diabetes, cardiovascular diseases and cancer are the leading cause of death worldwide. Together with chronic respiratory and mental disorders, they account for an estimated 86% of deaths and are responsible for 77% of the disease burden in Europe[1]. For most of these conditions, a healthy lifestyle could dramatically reduce the number of premature deaths. Refraining from tobacco and alcohol abuse, adhering to a healthy diet and regular physical activity are just a few examples. The success of prevention campaigns is best documented in the reduction of lung cancer rates following the first anti-tobacco campaigns and advertisement bans in the 1970s. Most NCDs are chronic in their course, which – in combination with an ageing population – leads to an increasing burden on healthcare systems.

“ Noncommunicable diseases (NCDs) such as diabetes, cardiovascular diseases and cancer are the leading cause of death worldwide. Together with chronic respiratory and mental disorders, they account for an estimated 86% of deaths and are responsible for 77% of the disease burden in Europe.

Moreover, increased international travel and mobility, globalised trade (especially in food) together with climate change and environmental pollution are affecting living conditions and promoting the spread of infectious diseases. Among infectious diseases, influenza puts the biggest burden on our societies, followed by tuberculosis and HIV.[2] For example, common waves of influenza kill around 44 000 people every year in Europe. The apparent weakness of our current health systems in responding to emerging infections and pandemics – including and especially the current outbreak caused by the COVID-19 coronavirus, but also recent outbreaks of the Ebola and ZIKA viruses – is of serious concern.

While extreme weather conditions are already affecting the health and well-being of European residents, especially elderly people, climate change and its impact on ecosystems also changes the regional distribution of infectious diseases. Europe is expected to face more infections due to subtropical and tropical pathogens[3]. Regrettably, another major threat involves the formation of antibiotic-resistant bacteria and the re-emergence of viruses that were once defeated or considered almost defeated in Europe, including some of the most infectious known diseases, such as polio and measles.

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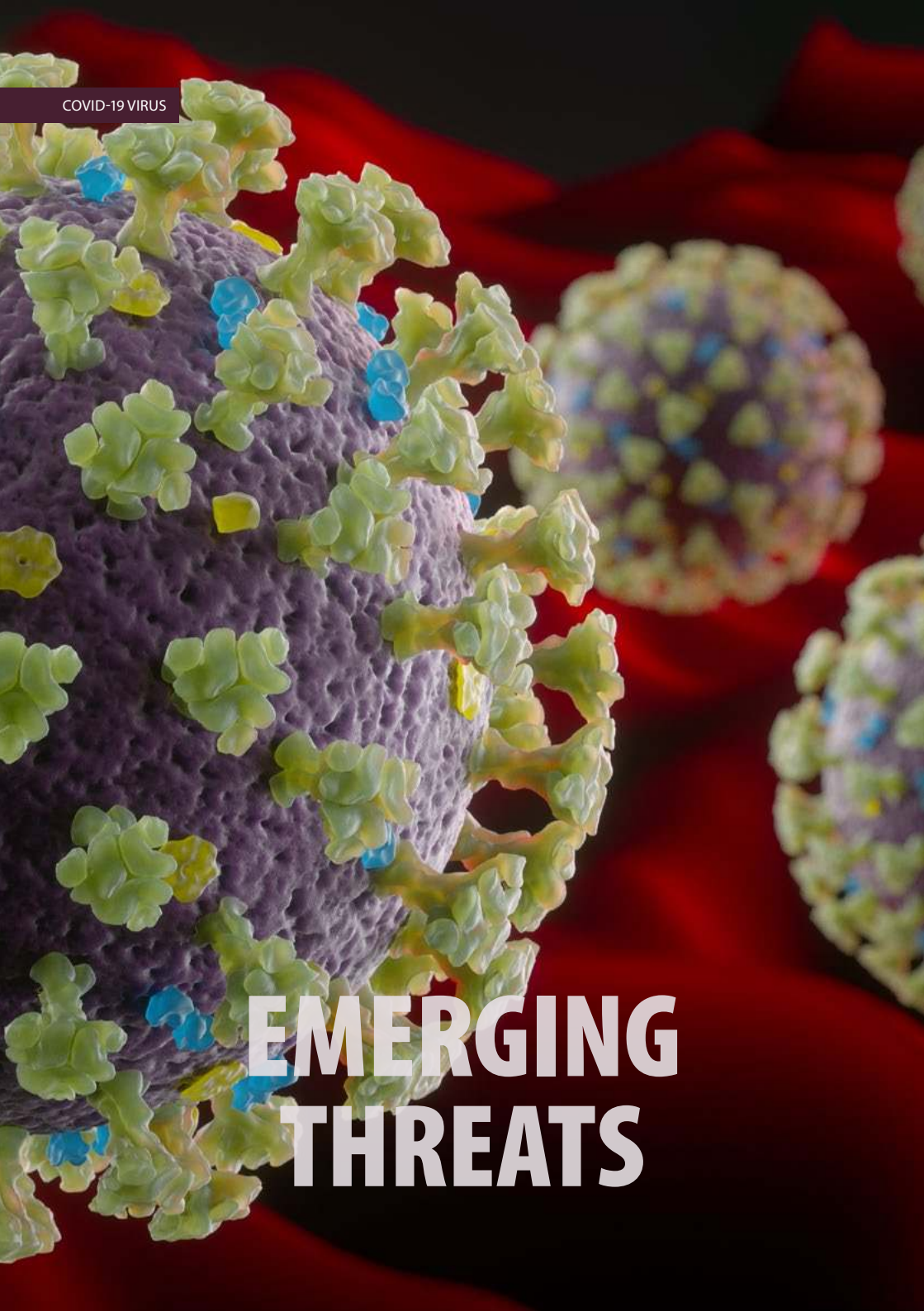

EMERGING THREATS

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The recent outbreak of COVID-19 documents both the power and the limits of scientific progress. When a pneumonia of unknown cause started emerging in China at the end of December 2019, it was literally just a few days or weeks before the coronavirus was isolated, its full genetic sequence published and several molecular details known. We witnessed an unprecedented global effort of information sharing, not only involving scientists, but also publishing houses, governments and health authorities – and yet this could still not prevent COVID-19 from turning into a pandemic. This is largely due to our globalised lifestyle, but also due to the fact that public health systems across the world were not unified in a global response to the expanding pandemic. People turn towards science at these critical moments, but scientific progress takes time – especially when it comes to the development of new vaccines and therapeutics. The current predictions are that the world scientific community will require at least another year to develop a safe and effective vaccine, which is likely to be the most efficient way of blocking the spread of the virus.

In the light of the COVID-19 pandemic, it is even more ironic that opposition to vaccination poses a major public health threat in European societies. Unfortunately, for several virus-borne diseases, the proportion of people being vaccinated is no longer sufficient to provide protection. We are witnessing a comeback of severe outbreaks of measles and other transmittable diseases, for which safe and effective vaccines are available. Measles is one of the world's most contagious infections, and can lead to serious, fatal complications in children. While fatalities may be low in Europe compared to developing countries, numbers have been continuously rising in recent years[4]. Both scientists and the media are partly responsible for the growing opposition to vaccines. While the false claim about a link between certain vaccines and autism made headlines worldwide, scientific research disproving the connection took too long to materialise and failed to resonate. In addition, science in this case did not manage to self-correct efficiently, as it ultimately took 12 years to retract the flawed paper from the prominent medical journal The Lancet, a vacuum into which the vaccine doubters were rapidly spreading.

FOMO SYNDROME (FEAR OF MISSING OUT) AND NOMOPHOBIA (SHORT FOR "NO-MOBILE-PHONE PHOBIA") ARE TWO EMERGING DISORDERS CAUSED BY DIGITALISATION

> **“This transformation is affecting a variety of age groups in different ways – from increasing social isolation, to a sedentary lifestyle, depression, and miscommunication.**

On top of these existing challenges comes another: the digital transformation of society. This transformation is affecting a variety of age groups in different ways – from increasing social isolation, to a sedentary lifestyle, depression, and miscommunication. The digitalisation of society is leading to new types of disorders, such as FOMO syndrome (Fear of Missing Out) and Nomophobia (short for “no-mobile-phone phobia”). The World Health Organization (WHO) declared gaming disorder a disease in 2018. Younger generations’ use of existing and new technologies will have a long-lasting impact on their physical and mental health.

MACHINE LEARNING FOR NEW THERAPIES

New technologies provide a positive impact for health challenges. They allow for faster, more precise diagnosis of many diseases, enabling treatment to start sooner. Thanks to the "omics" technology revolution[5], access to the relevant data in a patient is no longer a bottleneck. Rather, it is the integration and interpretation of data that present the greatest challenge. In this context, computational sciences and artificial intelligence (AI) are beacons of hope. Machine-learning algorithms are at an advanced stage: they can help to both develop new therapeutic strategies based on data integration and interpretation, and monitor patient response to therapies. For example, single-cell sequencing, genome comparison (between individuals or during the course of a disease), digital imaging and clinical proteomics[6] are currently used to detect unique lung diseases or specific breast cancer cells. Based on imaging data, AI systems are already able to diagnose diseases as reliably as – if not better than – a medical doctor. Only a few years ago this was implausible to many experts.

"Machine-learning algorithms are at an advanced stage: they can help to both develop new therapeutic strategies based on data integration and interpretation, and monitor patient response to therapies.

While big pharma's work with AI is still at an early stage, a rising number of startups are moving machine learning further onto the drug discovery stage. In 2017, the BenchSci Blog[7] identified 37 startup companies using AI to create new drugs. In 2019, the number increased to 177. Together, these companies have 62 drugs in their pipelines, with a few being advanced to late-stage clinical trials. Besides helping to design new molecules for targeted therapies, AI should help boost the systematic repurposing of existing drugs for new therapies.

LONG-TERM COMMITMENT TO BASIC SCIENCE – THE EXAMPLE OF HIV

The history of HIV is a prime example of how public health has advanced through basic science and modern technologies. At the same time, it also tells the story of how scientific progress may take decades to succeed, and how endurance pays off in the end. AIDS emerged as a pandemic in the early 1980s. A few years later, the HIV virus was identified by a team of scientists at the Pasteur Institute in Paris. That discovery enabled the development of the first commercial HIV test by 1985. The knowledge of the nature of the HIV infection gave rise to global prevention campaigns, which together with viral tests limited the spread of the disease.

“ Besides being a tale of the limits of science, the history of HIV/AIDS is also one of the inequalities of access to healthcare globally.

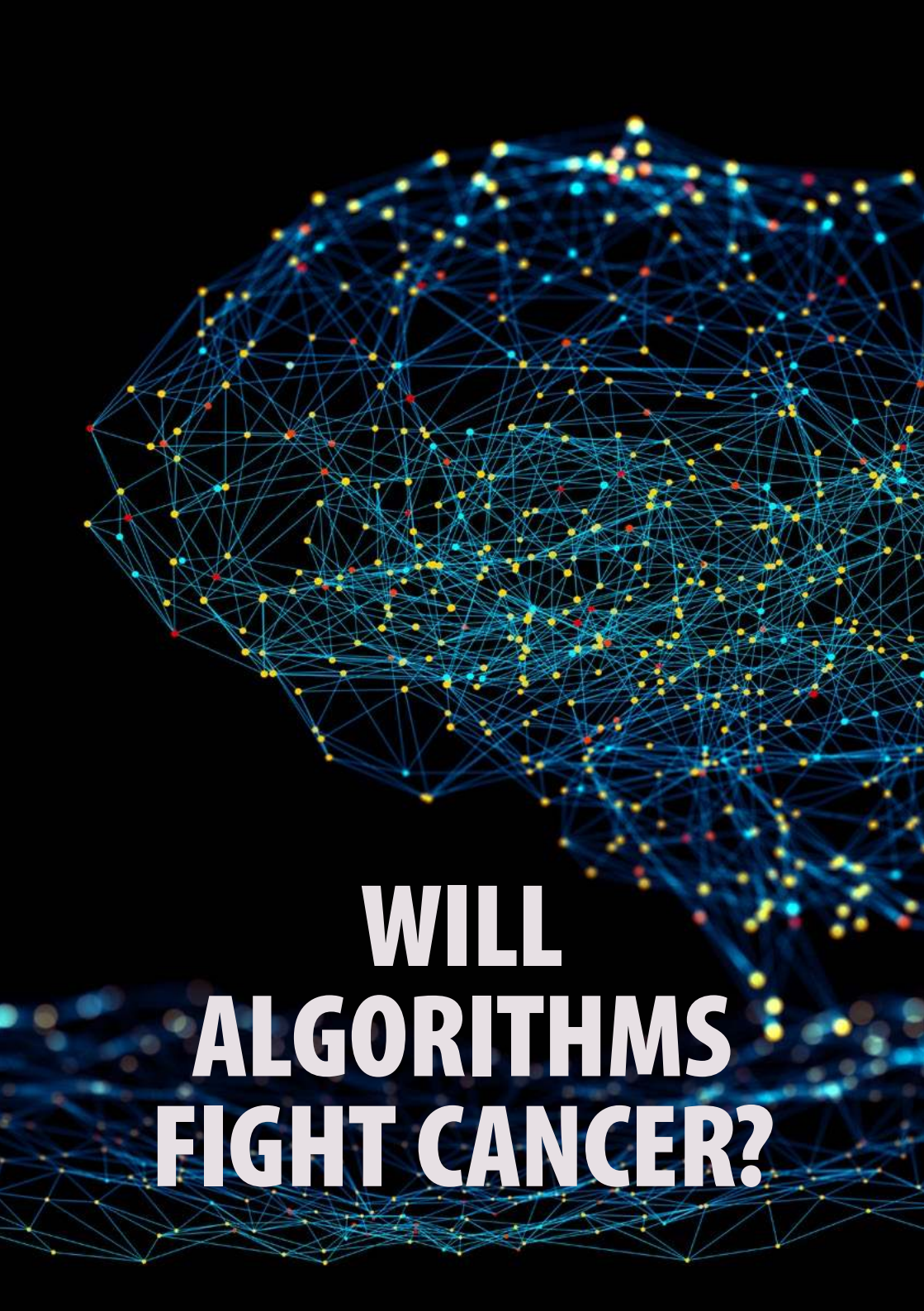
The first anti-HIV treatment, azidothymidine, is a repurposed drug which had originally been developed as a potential cancer treatment. It decreases opportunistic infections in HIV patients and thus AIDS-related deaths. While it ameliorates the symptoms and lethality of AIDS, it cannot purge the virus from patients; on the contrary, therapy-resistant viruses started to emerge very rapidly. Despite boasting announcements, and heavy financial investment into research, it took almost another decade before the United States Food and Drug Administration (FDA) approved the first tailored inhibitors of other critical HIV enzymes in 1995. More efficient drugs soon followed, and it turned out that HIV can be controlled and reduced below detection level by a combination therapy with several drugs. Besides being a tale of the limits of science, the history of HIV/AIDS is also one of the inequalities of access to healthcare globally. While AIDS-related deaths have decreased by more than 55% since their 2004 peak, rates for new infections are still increasing in some countries and pose particular difficulties in Africa, with 25.7 million people living with HIV in Africa, 2.4 million in Europe, and 37.9 million worldwide[8].


PROTEIN CLUSTERS
EVERY DISEASE
IS DIFFERENT

EVERY DISEASE IS DIFFERENT

In the first two decades of this century, we gained a basic understanding of how genetic variation relates to symptoms in a set of common diseases, an effort heavily supported by European funding organisations and charities such as the Wellcome Trust, which is one of UK's largest charitable foundations funding health-related research[9]. However, translating this wealth of knowledge into improved diagnostics, new drugs and treatments has only just begun.

The function of large parts of the genome are still entirely unclear, including the majority of the genome that does not contain gene coding for proteins and which was long thought to be evolutionary "baggage". We know which genetic variations cause the development of human disease – often these are single base changes called single nucleotide polymorphism (SNPs) – but in most cases we do not understand how a specific variation alters normal function. Nor do we understand the influence of the many other genetic variations individuals are likely to carry, or their interplay with lifestyle and environmental factors. Uncovering the molecular mechanisms at work and understanding their regulation and interactions in differing contexts will reveal differences between patients and will lay the foundation for therapeutic strategies for individual patients.

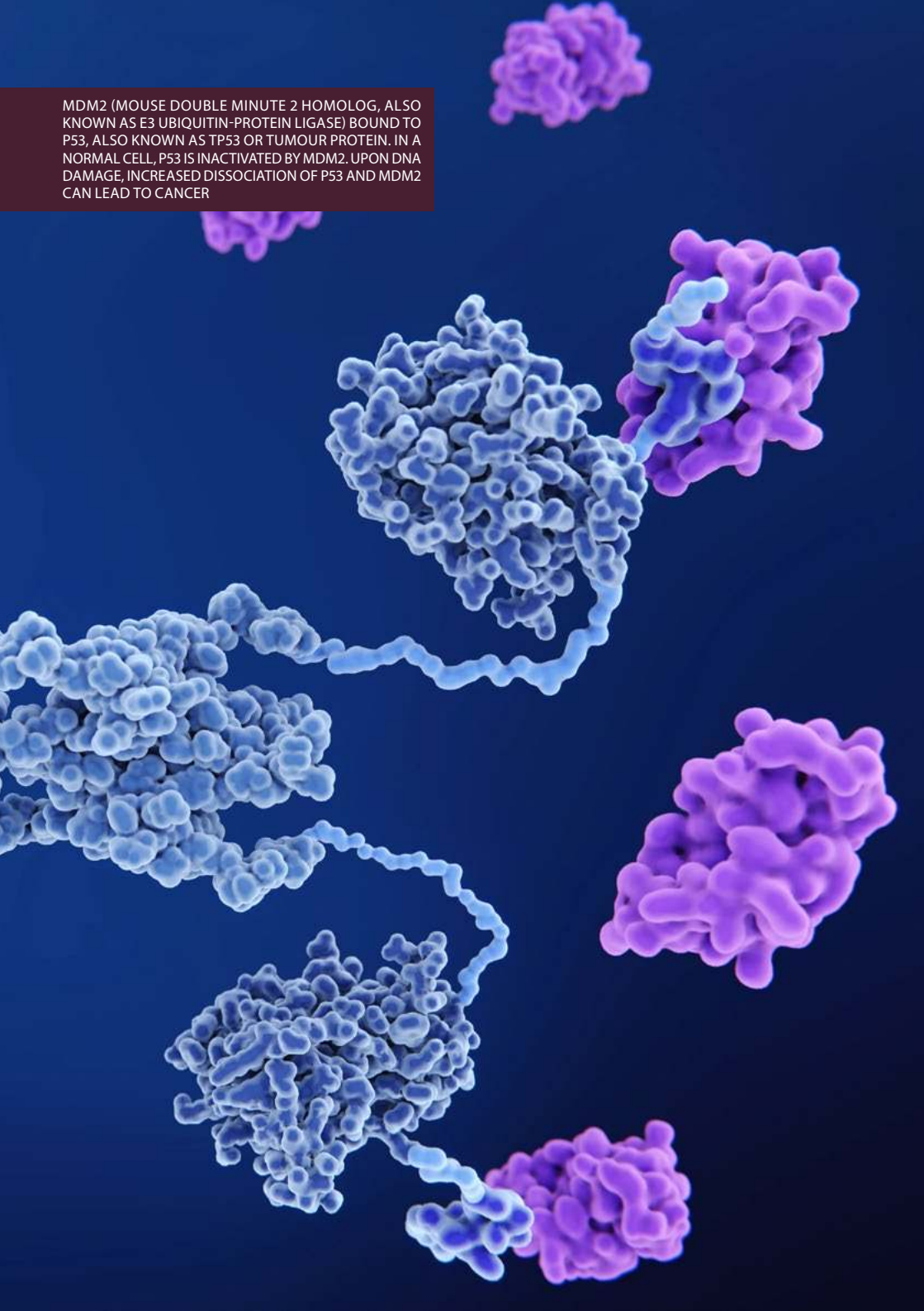

WILL
ALGORITHMS
FIGHT CANCER?

WILL ALGORITHMS FIGHT CANCER?

For humans, developing cancer is a multi-step process characterised by genetic instability and cellular changes, which are driven by the random and unpredictable nature of accelerated evolution. Cancer is not a single disease, but a unique set of genetic or molecular change that drives the uncontrolled proliferation of specific cells that ultimately leads to physiological malfunction. As a result, there are thousands of different types of transformed cells within a tumour, thus complicating treatment. Despite these sobering characteristics, we have gone a long way in improving the treatment of tumours over the last few decades. Until now, cancer patients have usually been treated with powerful inhibitors of cellular growth. This approach is called chemotherapy and usually has dramatic side effects as all cell growth in the body is affected. Indeed, these therapies are so invasive and unspecific that cancer patients are by now probably the greatest beneficiaries of the molecular biology revolution. Scientific breakthroughs resulting from insights into the molecular mechanisms underlying cancer development have revolutionised therapeutic treatments.

“Cancer patients are by now probably the greatest beneficiaries of the molecular biology revolution , diagnosis has taken a quantum leap, enabling an early identification of people at risk, and determining the exact tumour type.

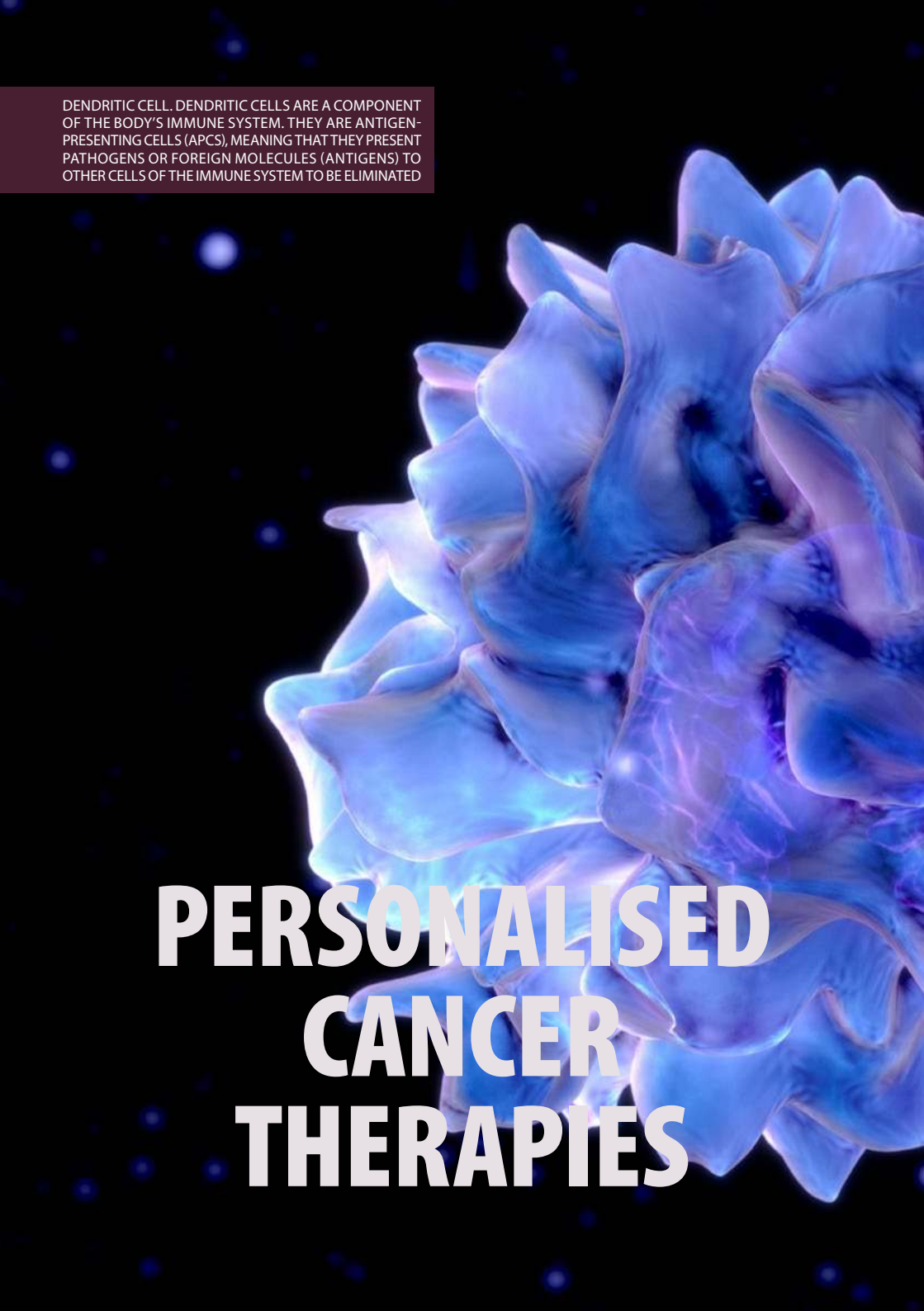
While conventional treatments, such as radiotherapy and chemotherapy, continue to play a central role with their ability to kill cancer cells, they now tend to be combined with more targeted approaches, most recently with successful immune therapies. In addition, diagnosis has taken a quantum leap, based on monitoring biomarkers in the blood or genetic testing for relevant mutations, enabling an early identification of people at risk, or already affected, and determining the exact tumour type. Many cancers are treatable at an early stage, and therefore early diagnosis promises to have the largest near-term impact on patient survival.



MDM2 (MOUSE DOUBLE MINUTE 2 HOMOLOG, ALSO KNOWN AS E3 UBIQUITIN-PROTEIN LIGASE) BOUND TO P53, ALSO KNOWN AS TP53 OR TUMOUR PROTEIN. IN A NORMAL CELL, P53 IS INACTIVATED BY MDM2. UPON DNA DAMAGE, INCREASED DISSOCIATION OF P53 AND MDM2 CAN LEAD TO CANCER

Targeted tumour treatments initially started with the inhibition of specific oncoproteins involved in controlling cellular growth. Drugs included monoclonal antibodies[10] that block growth receptors on the surface of cancer cells. A prominent example is trastuzumab (Herceptin®), the first approved molecularly targeted drug for HER2-positive breast cancer.

Other drugs include small chemical compounds that disrupt the oncogenic signalling initiated by those receptors. One example is vemurafenib (Zelboraf®), the chemical inhibitor of the growth-signalling molecule B-Raf. It is used for melanoma patients displaying a characteristic mutation in the B-Raf gene leading to uncontrolled cellular growth. There are currently more than 20 targeted therapies used in hospitals and these drugs have already helped millions of patients. Yet, the rapid development of tumour resistance to these therapies – usually within months of total apparent remission in patients – is a major problem. For this reason, attempts are made to use several variants of the original drugs, which are then supposed to be effective in the newly developed tumours that have become resistant to the initial agent. Moreover, a combination of two or more targeted therapies is increasingly used to maximise the efficiency of an anti-cancer treatment right from the start.



DENDRITIC CELL. DENDRITIC CELLS ARE A COMPONENT OF THE BODY'S IMMUNE SYSTEM. THEY ARE ANTIGEN-PRESENTING CELLS (APCS), MEANING THAT THEY PRESENT PATHOGENS OR FOREIGN MOLECULES (ANTIGENS) TO OTHER CELLS OF THE IMMUNE SYSTEM TO BE ELIMINATED

PERSONALISED CANCER THERAPIES

PERSONALISED CANCER THERAPIES

Another boost in treatment comes from the field of immunotherapy, which aims to reprogram the patient's immune system to identify and eradicate growing tumours. A new variety of drugs called checkpoint inhibitors turn immune cells into weapons that destroy tumour cells. A similar approach relies on a genetic modification of the patient's immune cells, turning them into superweapons for finding and destroying tumour cells in the body. Immunotherapy and its molecularly targeted drugs are about to revolutionise the treatment of multiple cancer patients, with extremely positive data from ongoing clinical trials.

Despite these irrefutable achievements, the public is slow to appreciate the advances. One reason is that cancer, particularly when diagnosed at a late stage and already spread to other sites within the body, is still the second major cause of premature death. Unfortunately, tumours are extremely complex and diverse, hardly any two are alike, and identification of the most effective targeted therapy is still a major challenge. At the same time, tumour cells are genetically instable and prone to mutate, causing them to quickly change their composition during therapeutic treatment, which often results in resistance towards applied drugs. With healthcare moving at lightning speed towards personalised approaches, the next decade will see plenty of fundamental changes in cancer therapy, especially if cheaper technologies enable routine analyses of the full tumour genome and proteome.

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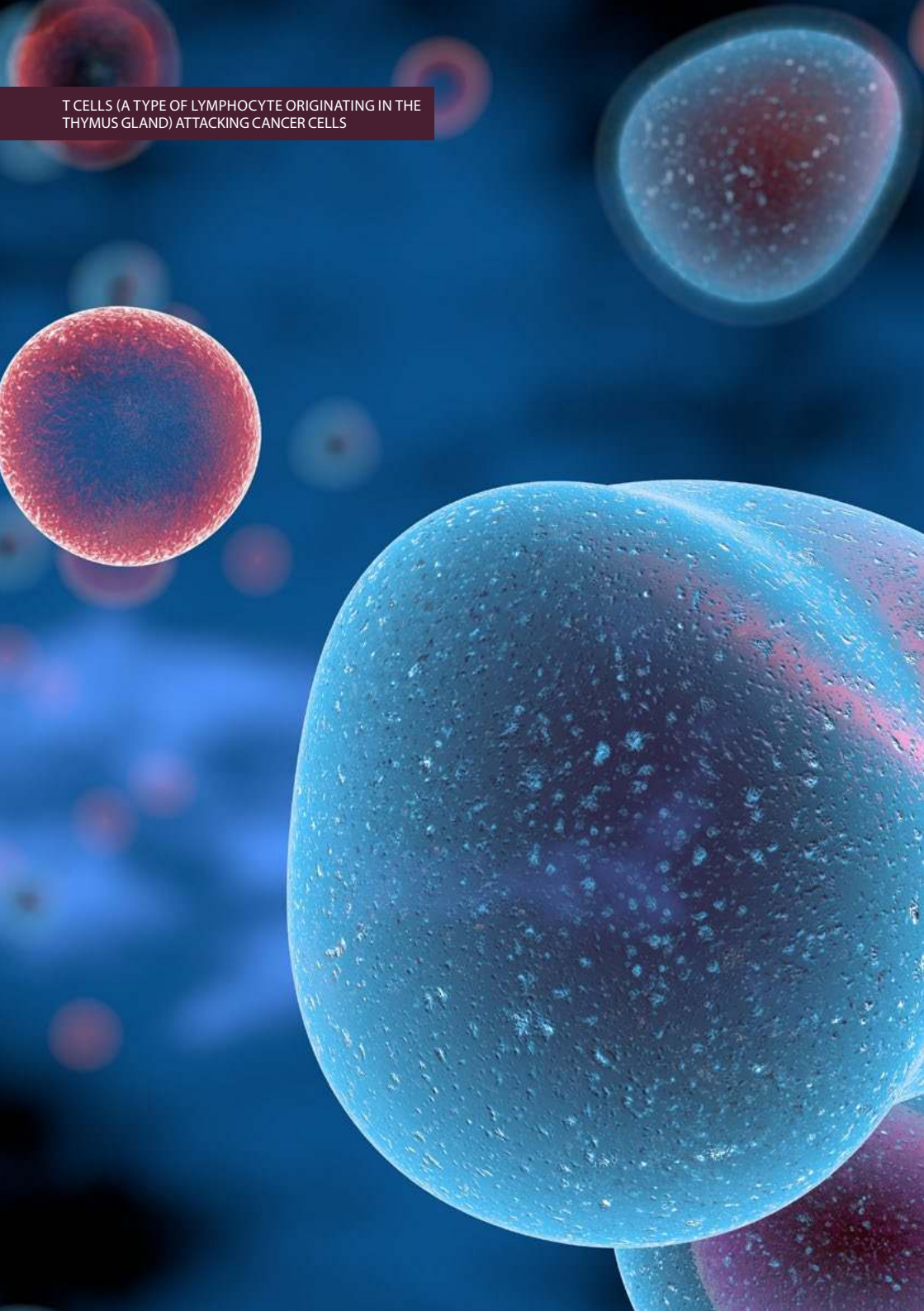


T CELLS (A TYPE OF LYMPHOCYTE ORIGINATING IN THE THYMUS GLAND) ATTACKING CANCER CELLS

Personalised approaches in cancer therapy require significant investment in technologies for analysis, data integration and the development of new predictive algorithms. With increased knowledge of individual tumour mutation profiles, new targets will emerge and new drugs will be developed. Fortunately, the development of high-throughput screening (HTS)[11] technologies – such as the use of gene scissors CRISPR/Cas9) to change specific segments in the genetic code – has equipped us with powerful tools to identify tumour cell vulnerabilities, enabling us to better predict the susceptibility of a tumour to a given combination of drugs and potentially even to correct mutations in hereditable forms of cancer or other heritable diseases.

These technologies also open the door to systematic efforts to repurpose already approved drugs by testing which combination might be effective against specific tumours. Such approaches have the potential to significantly reduce the long time to clinical application of novel therapeutic concepts.

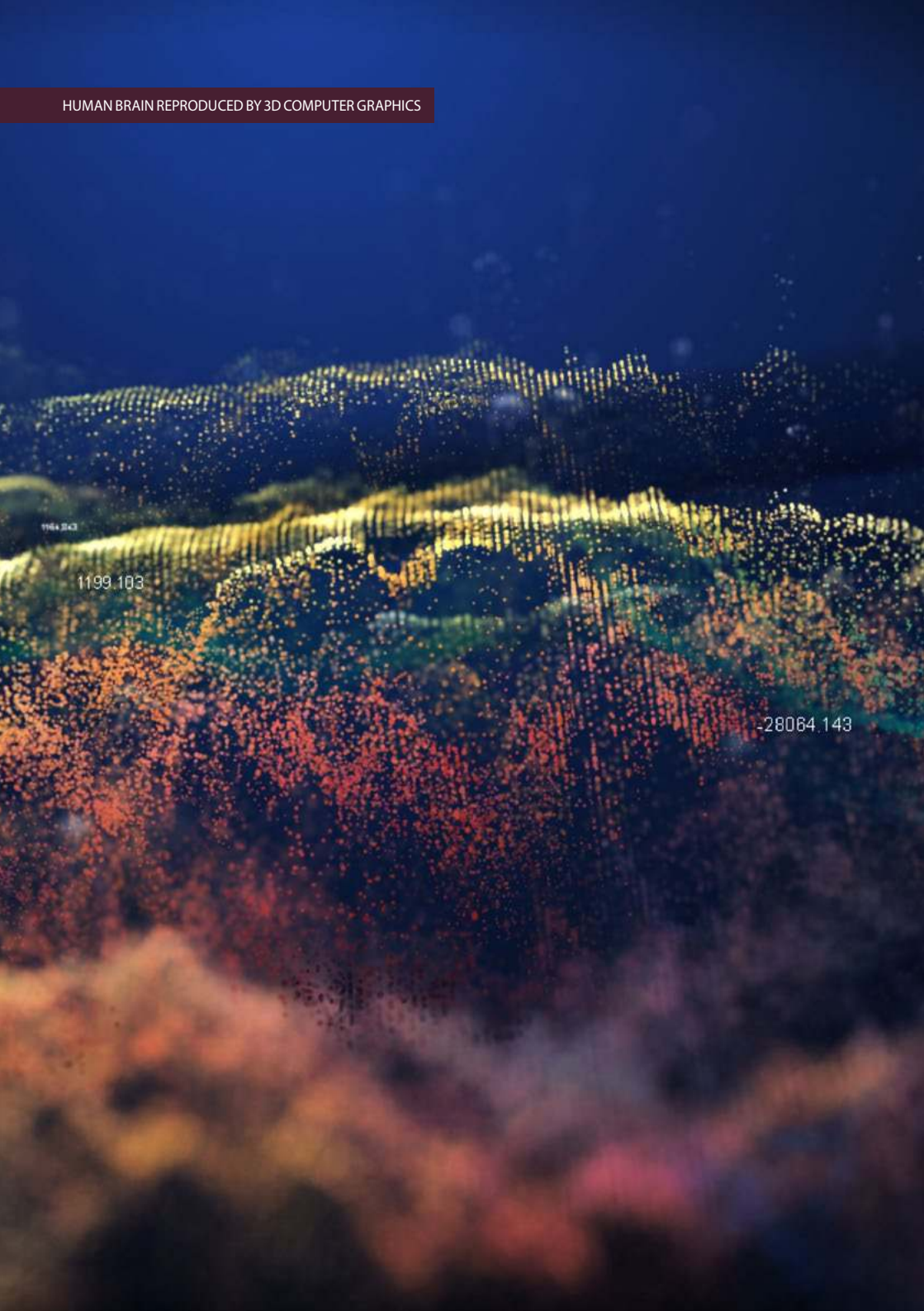

THE WORLD IS
GETTING OLDER

THE WORLD IS GETTING OLDER

The number of people above 60 is expected to double by 2050, reaching around 2.1 billion people worldwide. This increase is most pronounced in Japan and the European Union[12]. An ageing population brings another challenge to the forefront of medicine: neurodegenerative diseases such as Alzheimer's, Parkinson's and dementia. Patients with these diseases suffer from a progressive destruction of nerve cells in the brain and/or spinal cord, leading to impaired movement coordination, mental dysfunctions, or both. It is foreseeable that neurodegenerative diseases will culminate in a healthcare crisis by the middle of the 21st century, with Alzheimer's having the biggest impact. By 2050, the number of patients suffering from these disorders is estimated to more than triple, placing a significant burden on affected families, public healthcare and entire societies.

"Neurodegenerative diseases will culminate in a healthcare crisis by the middle of the 21st century, with Alzheimer's having the biggest impact.

Neuronal degeneration is mostly caused by the accumulation of dangerous deposits – often clumped-together proteins – and damage to the functional units within the cells, so-called organelles (mitochondria, endoplasmic reticulum, lysosomes) of long-living neurons. These developments lead to slow, progressive damage and eventually the death of specific groups of neurons in the brain. Based on this knowledge, scientists now aim to identify very early events in the development of neurodegeneration that can be inhibited before the damage accumulates and causes a massive loss of neurons. Obviously, this is a tricky situation, as therapies – to be successful – may have to start 10 to 20 years before the first symptoms appear, at the time when deposits first start accumulating in neurons. Currently, we lack non-invasive diagnostic tools to detect this stage, for example by mass screening the whole population. Once neurons have started dying, stopping the domino effect of disease is much less likely. For example, approximately 80% of dopaminergic neurons (neurons that synthesise the neurotransmitter dopamine, which is required for the healthy functioning of the nervous system) begin to atrophy before first clinical symptoms of Parkinson's disease appear, indicating



HUMAN BRAIN REPRODUCED BY 3D COMPUTER GRAPHICS

that there is a long therapeutic time window. Similarly, in Alzheimer's disease, damage within hippocampal neurons, which are critical for memory connections, often accumulates for many years before the nerve cells lose their functions.

So far, none of the aforementioned neurodegenerative diseases is curable and treatment has only dealt with the late-stage symptoms, delaying progression of the disease at best. Multiple reasons exist for this. First, we have to consider the incredible complexity of the human brain. It has about 86 billion neurons, each having about 7 000 synaptic connections to other neurons. Secondly, the non-dividing, long-lived nature of neurons make them prone to accumulation of damage during their lifetime. Thirdly, the brain is a secluded organ, difficult to approach for diagnostics or to administer conventional drugs. Altogether, targeting neurodegenerative diseases is one the greatest challenges in biomedicine today.

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Until now, most drug development for neuronal degeneration has focused on using chemical compounds, antibodies, nucleic acids or proteins able to prevent and possibly reverse the build-up of the proteins that can cause the disease, such as synuclein for Parkinson's and amyloids for Alzheimer's. However, all attempts to target aggregation-prone proteins with the above-mentioned therapies have so far fallen short of expectations. More recently, attention has been focused on the cells' own quality control systems, which are responsible for removing any dangerous deposits or damaged organelles. Defects in those cellular control systems may contribute to or even cause neurodegeneration. At the same time, boosting the performance of those internal mechanisms may have a protective effect. One of those is autophagy, which enables cells to remove damaged or dangerous material from our body. Novel innovative approaches try to flag dangerous components and target the autophagic waste machinery for their removal.

IN THE FUTURE, CARE AND HEALTH IN HOSPITALS WILL RELY SIGNIFICANTLY ON THE INTERACTION BETWEEN DOCTORS AND ROBOTS

WHAT'S NEXT

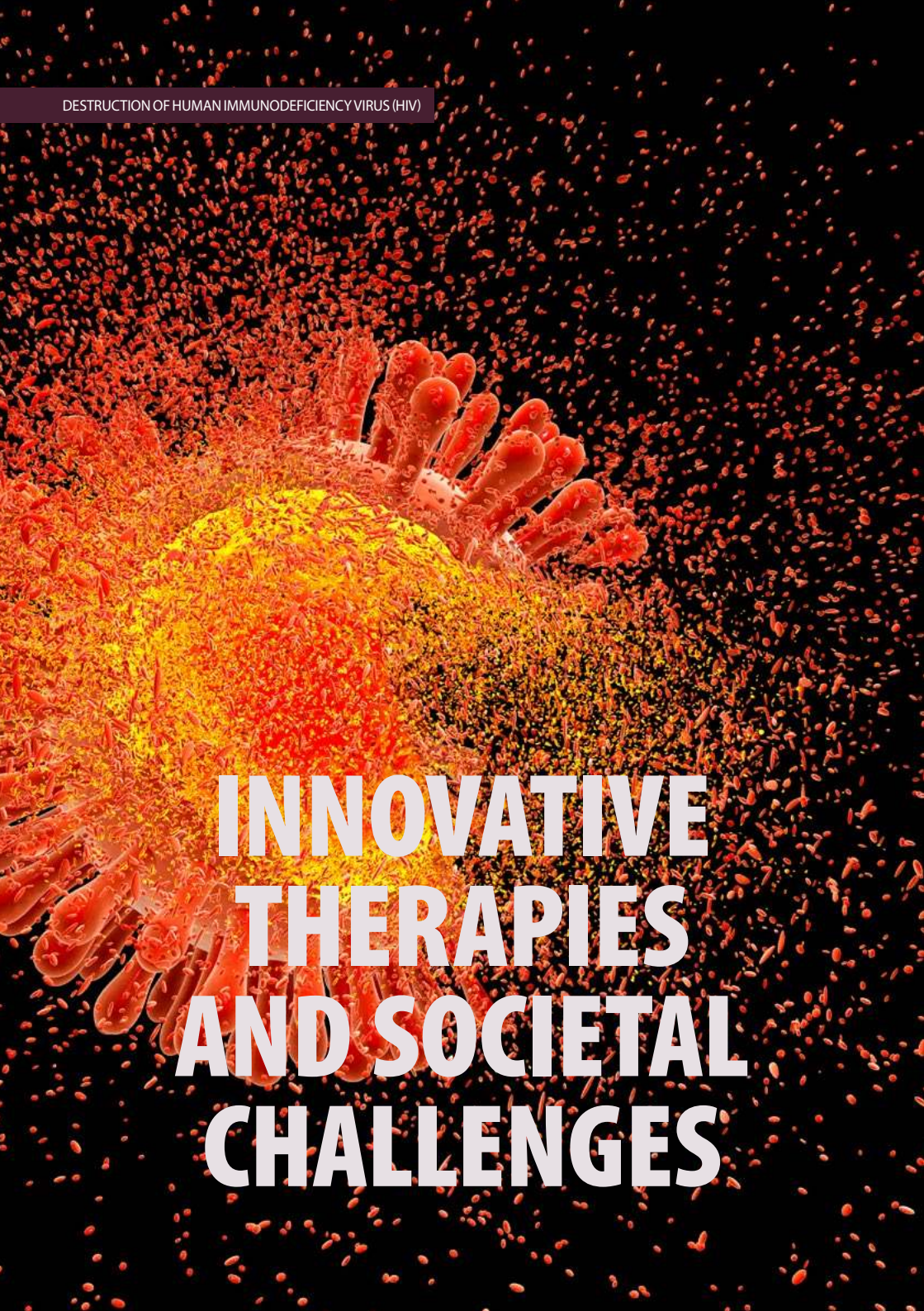
WHAT'S NEXT

The digital revolution has already made a big impact on patient care, starting with the wealth of (not always medically verified) information available online and mobile apps that can record and share health-related data with remote doctors (part of a wider trend towards the remote monitoring of patients). With the ability to rapidly and affordably sequence the whole human genome, tailoring therapies to a patient's genetic background is finally within reach.

> **"CRISPR/Cas9 technology enables extremely precise, rapid and cost-effective intervention in the genetic material of living organisms.**

The unprecedented opportunities presented by super-computing, machine learning and AI go hand-in-hand with ethical concerns and profound fears for the future of medicine. Nowhere is this as apparent as in the field of genetic engineering. The revolutionary CRISPR/Cas9 technology[13] enables extremely precise, rapid and cost-effective intervention in the genetic material of living organisms. This technique not only offers amazing opportunities in ecology and food production, but also in the discovery of the causes of diseases and the development of new therapies to treat human disorders. The technology, however, can also be (mis)used to generate genetically modified or "optimised" human beings. Furthermore, it remains unclear if the method really has no off-target effects on the genome in all cases, which could cause undesired, heritable consequences in patients undergoing gene therapy.

The CRISPR/Cas9 system was first applied as a tool for genetic engineering in 2012. Six years later, the birth of potentially HIV-resistant genetically modified babies was reported in China and highly criticised around the world for ignoring well-established international norms in research ethics. The scientist behind these efforts was recently sentenced to three years in prison for violating research integrity law in China[14]. Germline genetic modification, or the process of genetically modifying sperm or egg cells for the purpose of reproduction, is forbidden in 16 of the European Union's 27 Member States. European researchers have traditionally been among the first to voice concerns about the dangers and ethical implications of genetic engineering for therapeutic purposes, and the problems posed by the large-scale access to and use of genomic data. However, in a globalised world neither technical breakthroughs nor the consequences of misuse can be limited to national borders.



INNOVATIVE THERAPIES AND SOCIETAL CHALLENGES

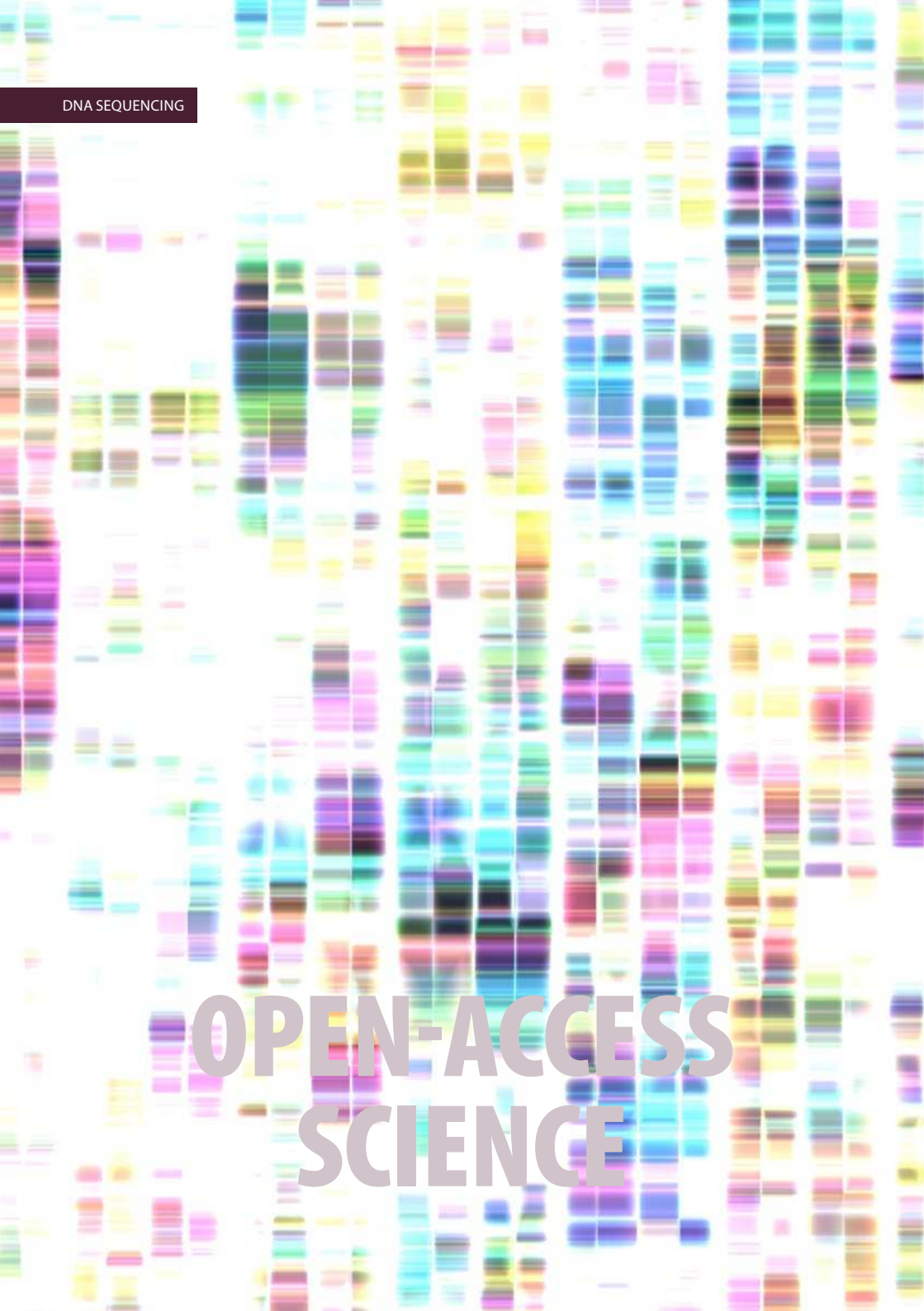
INNOVATIVE THERAPIES AND SOCIETAL CHALLENGES

Besides the concerns related to gene therapy and the potential misuse of individual genetic data, for example by insurance companies or digital firms, scientific and technological breakthroughs pose other ethical challenges. Many of the innovative treatments come with skyrocketing costs, putting an additional strain on limited healthcare budgets and raising questions of the accessibility of high-level, individual care and of inequalities in the healthcare system.

“Is it justifiable to cover treatment costs for a single patient while the same amount of money could be used to cure hundreds of people suffering from other diseases?

There is also a clear medical need to invest more in rare disease research, which is largely neglected by the pharma industry. When innovative treatments for rare diseases are developed, they often come with an astronomical price tag. High prices are only partially the result of a small market for such treatments. Uniqueness, rather than demand, often dictates pricing, and only regulations can solve the issue.

With tailored therapies for common diseases being introduced on a broad scale, physicians will more frequently have to ask themselves: is it justifiable to cover treatment costs for a single patient while the same amount of money could be used to cure hundreds of people suffering from other diseases? Should this treatment be covered by the public health system or should it be funded privately? To give an example, current cancer therapies with genetically modified patient cells discussed earlier in this article cost several hundred thousand euros. However, to efficiently target the unique personal circumstances leading to a disease, and to provide the needed benefit to patients while at the same time decreasing the unwanted effects, individual therapy treatment is a must. We will have to debate how to overcome the financial hurdles. A similar debate arose around the high cost of treating new chronic diseases that were previously fatal and now require lifelong treatment with expensive medication, such as HIV infection, which can now be controlled by a combination of drugs. And while these developments force us to face some extremely difficult questions, the much more pressing issue of how to ensure acceptable healthcare standards and accessibility worldwide has not even been touched on.


DNA SEQUENCING
OPEN-ACCESS
SCIENCE

OPEN-ACCESS SCIENCE

Is there a solution to control high healthcare costs? Sustainable healthcare systems could be built on a few key concepts: high standards, fair pricing, efficient organisation, open science, a well-informed public and a well-educated professional community.

From an academic point of view, open-access to scientific research will significantly decrease the price of drugs and should be mandatory for publicly funded research. The International Human Genome Sequencing Consortium, which pulled together forces from around the world, played a pioneering role in making a full genome sequence publicly available. Since then, many publicly funded, large-scale biomedical projects have followed in the Consortium's footsteps, with growing amounts of data being shared in easily accessible databases. Fund providers and policymakers within the European Union, such as European Commission-funded research and charitable foundations, have championed open science policies.

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Despite these efforts, drug development and pricing for new treatments is still dominated by manufacturers, who in turn use publicly funded scientific research. A new era, however, may be dawning. More public-private partnerships such as the Structural Genomics Consortium have emerged, where scientists from academia and industry work together to discover new medicines through open-access research. Their research record has already proven that open science is successful and can have a sustainable impact on drug development, education and societies. Moreover, new funding models for integrative academic-industrial research and the use of cutting-edge technologies are needed as the current classical approaches for the development of new drugs, new antibiotics, tailored therapies and neurodegenerative diseases are not sufficient. A concerted effort similar to the Human Genome Project will be necessary to generate the tools and technologies to explore all proteins in the human proteome, and to manipulate those involved in disease pathways.

AUGMENTED REALITY GLASSES ENABLE PHYSICIANS TO INCLUDE DATA VISUALISATION IN TREATMENT PROCEDURES

SHARING RESPONSIBILITIES FOR THE FUTURE

SHARING RESPONSIBILITIES FOR THE FUTURE

Changing the culture of drug research from a pharma-driven process to disease-focused, personalised treatments will eliminate often-futile research cycles and decrease the cost of drug development. The European Union could save at least €10.2 billion a year if FAIR (findable, accessible, interoperable, reusable) data principles were fully implemented[15]. The research dilemma cannot be solved by scientists and clinicians alone, but rather will need to involve insurance companies, government, the pharma industry and the public.

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Ensuring fair access to high quality healthcare will depend on our ability to offer the most efficient therapies and care to all patients, regardless of the ailment. Advances in science and technology may drive progress in medicine and healthcare, but only shared responsibilities and common policies around the globe will make it possible.

Notes

[1] http://www.euro.who.int/en/health-topics/noncommunicable-diseases

[2] https://www.eurosurveillance.org/content/10.2807/1560-7917.ES.2018.23.16.17-00454#abstract_content

[3] FEMS Microbiol Lett. 2018 Feb 1;365(2). doi: 10.1093/femsle/fnx244.

[4] EMBO Mol Med 2018 10:e9176. https://doi.org/10.15252/emmm.201809176; https://www.who.int/csr/don/06-may-2019-measles-euro/en/

[5] Omics refers to the collective technologies used to characterise and quantify pools of biological molecules and to explore their roles, relationships and actions in the cells of a living creature. https://www.genomicseducation.hee.nhs.uk/blog/the-omics-revolution/

[6] The proteome is the entire set of proteins that is, or can be, expressed by a genome, cell, tissue, or organism at a certain time (Wikipedia).

[7] https://blog.benchsci.com/

[8] https://www.who.int/hiv/en/

[9] https://wellcome.ac.uk/

[10] Monoclonal antibodies (mAb or moAb) are antibodies that are made by identical immune cells that are all clones of a unique parent cell (Wikipedia).

[11] High-throughput screening (HTS) is a method for scientific experimentation especially used in drug discovery and relevant to the fields of biology and chemistry. Using robotics, data processing/control software, liquid handling devices, and sensitive detectors, high-throughput screening enables a researcher to quickly conduct millions of chemical, genetic, or pharmacological test. https://en.wikipedia.org/wiki/High-throughput_screening

[12] https://www.un.org/en/development/desa/population/publications/pdf/ageing/WPA2017_Highlights.pdf

[13] Simply put, the technology involves the injection of new genetic information into cells, coding for gene scissor Cas, which then enables the precise cutting of DNA at a specific site which can be pre-determined. This can be used to modify the genetic code, e.g. to change the function of genes or eliminate dangerous mutations.

[14] https://www.scientificamerican.com/article/crispr-babies-scientist-sentenced-to-3-years-in-prison/

[15] https://ec.europa.eu/research/openscience/index.cfm

BIOGRAPHY

Ivan Đikić was born in Zagreb in 1966. He is a leading expert in the fields of ubiquitin biology and cancer research, and is a professor at Goethe University Frankfurt and a fellow of Max Planck Society. He maintains an active research lab that enables multidisciplinary teams of scientists to study the molecular principles of life and discover pathological alterations that lead to the development of human diseases such as cancer, neurodegeneration and infection.

Ivan has received numerous awards for his scientific work, including the Ernst Jung Prize for Medicine and the Gottfried Wilhelm Leibniz Prize, the highest scientific honour in Germany. He is an elected member of the German Academy Leopoldina and the European Academy, as well as an honorary member of the American Academy of Arts and Sciences.

Ivan Đikić is committed to the education of future generations of scientists across the world. His efforts to popularise science among the public have been recognised with the highest civilian state honour, The Order of Duke Branimir, bestowed by the President of Croatia.

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