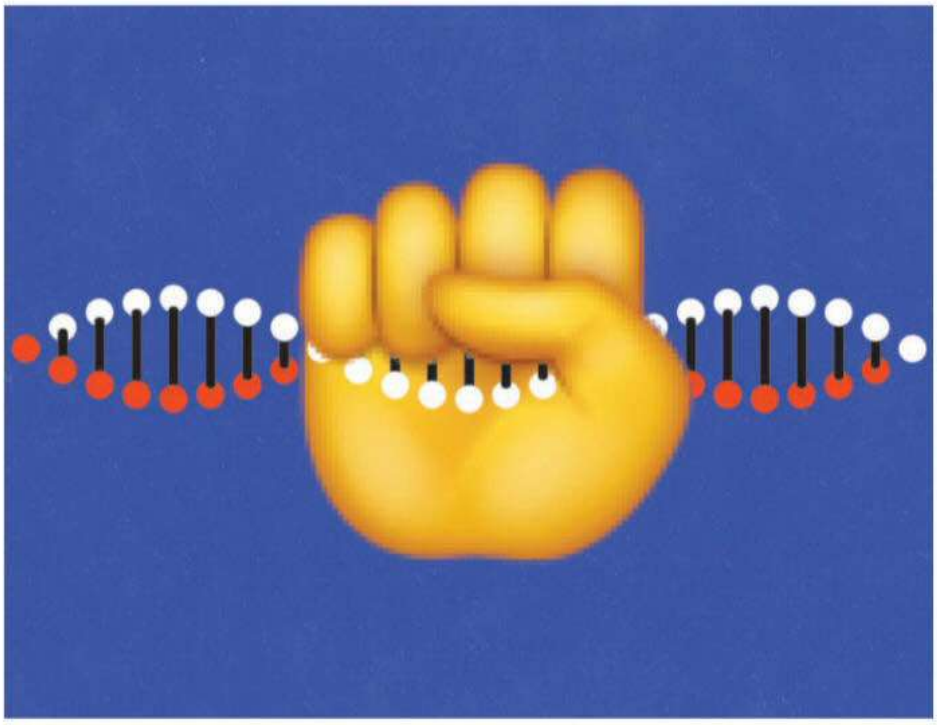
THE WORLD AHEAD

WHAT IF?

JULY 3RD 2021

Scenarios for the future of health

What If? is our annual collection of scenarios. This year it considers the future of health. Each of these stories is fiction, but grounded in historical fact, current speculation and real science. They do not present a unified narrative but are set in different futures



Freedom to tinker

October 2029

Members of a biohacktivist group demand the right to experiment with their own biology. An imagined scenario from 2029

TO UNDERSTAND THE controversy around the Witnesses of Bioinformatic Freedom (WBF), a biohacktivist group, cast your mind back to the coronavirus pandemic a decade ago. Within days of the discovery of the SARS-CoV-2 virus in 2019, its genome had been sequenced and used to create prototype vaccines containing molecules of messenger RNA, or mRNA. Hundreds of millions of people were injected with these artificial mRNA molecules, which instructed the protein-producing machinery inside the body's cells to make a "spike" protein, identical to that found on the virus's surface. The resulting spike proteins then triggered an immune response, priming the recipient's immune system so that it could recognise and fight off the virus if required to do so.

The same mRNA technology had been used in the 2010s to develop experimental vaccines for other diseases, including Zika virus and Ebola. But the power of mRNA was demonstrated on a global scale during the

7.5

The size (in kilobytes) of the genome of the SARS-CoV-2 virus

pandemic, paving the way for other treatments in the 2020s. Like the vaccines, these use carefully crafted mRNA messages to boost temporarily the production of needed proteins, or inhibit the production of harmful ones—a technique often likened to using the patient's own cellular machinery as an on-demand drug factory. This approach is now used to treat cancer, heart disease and neurological disorders.

The story of that medical revolution has been widely told. Less well known is the parallel story that has been unfolding alongside it. During the pandemic, new technologies, infrastructure and supply chains were created to manufacture mRNA vaccines at vast scale, while also allowing their mRNA payloads to be quickly and easily tweaked as new variants emerged. Once covid-19 was brought under control and demand for vaccines subsided, some of that infrastructure began to be put to new and unexpected uses.

The possibility of using mRNA for self-enhancement first emerged in 2024, after the Paris Olympics. In 2012, Katalin Karikó and Drew Weissman, two of the main actors in the intellectual development of therapeutic mRNA, had shown that carefully designed mRNA molecules could transiently raise the level of erythropoietin (EPO), a protein hormone which stimulates production of red blood cells, in mice. More EPO means more red blood cells, which means more oxygen delivered to working muscles, which improves physical performance. In the months after the Paris Olympics rumours began to circulate that some competitors had been taking regular injections of EPO-producing mRNA. But the tests available failed to show conclusive evidence of foul play. New tests were then developed in time for the 2028 games.

Meanwhile, a group of biology doctoral students at the University of Belgrade began producing and distributing an mRNA molecule said to enhance learning abilities by boosting the synthesis of small proteins involved in memory formation. The government launched an investigation after a student, Luka Dragotin, died of a mysterious autoimmune complaint in 2025. The test scores of the students who had been dosing themselves with mRNA did seem to have risen relative to those of their peers. The doctoral students went to prison for 15 years, and the government imposed strict new regulations on mRNA technology.

The following year *Wired*, a technology-news outlet, published a story about a group of mothers in Austin, Texas, who had dosed themselves with mRNA molecules during pregnancy. The treatment was said to keep their production of thyroid hormones within the optimal window for neurological development in utero, thus maximising the cognitive capacity of their offspring. None of the mothers suffered any complications in pregnancy, and the mRNA-dosed children all turned out to be healthy. But there was an outcry from evangelical Christians and right-wing politicians who denounced "meddling" with biology. In 2027 the federal government banned self-dosing with mRNA and set up a Senate committee to investigate the use and misuse of the technology.

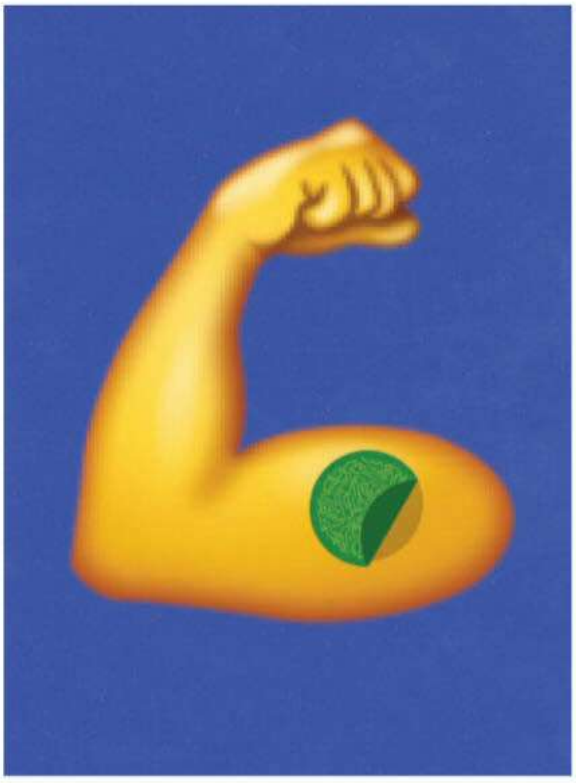
It was at this point that the WBF, a group championing biohackers' rights, stepped onto the public stage. It declared in its manifesto that people had the right to send genetic messages of their own making to their own cells. WBF members, it emerged, had documented successful mRNA dosing for alertness, minor tweaks to physiology (such as to prevent hair loss), and suppression of stress hormones. It was, they argued, already too late for governments to stop them.

The group has since turned out to have members and sympathisers throughout the research community, who have helped refine the process of delivering messages to human cells. Needles and syringes are no longer required. Biohackers have built small patches of flexible electronics and microfluidics, worn on the body much like a nicotine patch, capable of crafting specific mRNA sequences in situ and inserting them into the bloodstream. New sequences can be beamed to the patch from a smartphone or computer.

A flourishing open-source ecosystem has developed around the designs of the patches and the molecules they can produce. New mRNA molecules are usually released to a select group of alpha testers, and made widely available only after the alpha testers have granted approval. Not all mRNA molecules are therapeutics or enhancements; the fastest-growing category is for molecules that offer transient, drug-like experiences, supposedly with no long-term side-effects.

Some doctors are said to be quietly dabbling in mRNA hacking themselves, and even recommending it to patients. For their part, drug companies have called for a clampdown on what they deride as "amateur pharmaceuticals". They have also tried to have some repositories of mRNA molecules taken offline, claiming violation of intellectual property.

The question now is whether governments can put the genie back in the bottle through concerted, co-ordinated action. Many politicians say the power to tinker with biology is too dangerous to have in the hands even just of doctors and must be regulated. Next month's global meeting on the topic in Belgrade, the Dragotin Conference, will bring together policymakers, medical experts and regulatory specialists. Representatives from the WBF have not been invited. ●



↓ **Superforecast**

How many RNA vaccines and therapeutics for humans will be FDA-approved as of 2031?

Fewer than 10
2%

10 to 100
50%

101 to 249
38%

250 to 500
8%

More than 500
2%

Superforecaster probability predictions
Source: Good Judgment
Pit your wits against the superforecasters at GJopen.com/whatif

→ If America tackled its opioid crisis

The other epidemic

June 2025

Kamala Harris's administration is getting serious about tackling deaths from drug overdoses. An imagined scenario from 2025

PROJECTIONS FROM the Centres for Disease Control and Prevention (CDC) published this month predict that in 2025, for the first time, more than 100,000 Americans will die from a drug overdose, bringing the total to more than 1m since 1999. At current rates, by the time of the next presidential election in 2028, more Americans will have died in the 21st century of drug overdoses than died in all of America's wars over its entire history. These horrifying statistics have at last focused attention on this neglected crisis.

The roots of the problem go back a long way. Since the 1980s, America's drug-overdose death rates have increased at the terrifyingly steady clip of 7.6% per year. In 2018, when the death rate dropped for the first time in ages, the Trump administration took a victory lap much too soon, touting the success of its policies. Then came covid-19. Drug-overdose rates exploded as people sheltered in self-enforced quarantine, addiction-treatment clinics were closed and Mexican cartels established supply lines of cheap, potent drugs to all parts of America. The rising death toll was barely dented by the modest sums spent on the problem during the Biden administration, which did little more than twiddle its thumbs after Republicans took back control of Congress in the mid-term elections of 2022.

Though addiction to all types of drugs (including cocaine and methamphetamines) has steadily increased, the primary problem remains opioids. They came to the fore in the early 1990s in the form of prescription painkillers that were unscrupulously marketed to doctors as unlikely to cause addiction. The most famous was OxyContin, launched in 1996. By the time it had been reformulated to make it harder to abuse, too many Americans were already hooked and the drug crisis had morphed into something else entirely, as addicts looked for alternatives. "Reformulation led markets to sell deadlier substances and contaminate non-opioid drugs, expanding illicit opioid drug use," concluded David Powell and Rosalie Liccardo Pacula, two drugs-policy researchers, in 2020.

Prosecutors spent years in litigation against the makers of OxyContin and other opioid manufacturers and distributors, culminating in last year's momentous judgment and a penalty of $350bn—larger than that imposed on tobacco giants over their promotion of smoking. But few pharmaceutical executives went to jail, and this immense sum seems small, given that the crisis has lasted a quarter of a century and costs America $80bn a year, according to the CDC.

In addition to the cash from the settlement, Democrats in Congress, with the backing of the White House, now propose to spend an extra $250bn over the next ten years to tackle the problem (President Kamala Harris shares her predecessor's proclivity for eye-popping sums). It is something that a few Republican senators could even agree to—curtailing addiction being one of the only remaining bipartisan issues. The emerging consensus reflects a continuing shift in America's approach to drugs policy, with less emphasis on reducing the supply of illicit drugs via enforcement and incarceration, and more emphasis on reducing harm and the risk of death for those addicted.

The model for the new legislation is the Ryan White Care Act, passed in 1990 to deal with the HIV/AIDS epidemic by establishing the federal government as the payer of last resort for patients. It was part of a successful campaign against the disease, as the distribution of therapeutics rapidly reduced mortality, and prevention efforts stemmed the growth of infections. The introduction of a prophylactic treatment in 2012 has since helped keep rates of infection among vulnerable groups (mainly gay and bisexual men) in check.

There is now hope that similar progress can be made against drug addiction, particularly to opioids. The Food and Drug Administration (FDA) long ago approved three drugs to provide medically assisted treatment to those addicted to opioids: methadone, buprenorphine and naltrexone. The first two are opioids used as replacements, with less scope for abuse. The third blocks cells' opioid receptors and thus the euphoria from abusing drugs. All three medicines substantially reduce the risk of dying from an overdose.

Yet they are surprisingly underused. Only around half of those addicted to opioids in America receive ▸▸

these therapies. But for years their use has been hampered. Bureaucratic restrictions kept doctors from widely prescribing buprenorphine. The requirement that methadone be doled out in person remains, even though evidence shows that allowing it to be taken home reduces subsequent hospitalisations. Skittishness among non-specialist doctors limited the use of these treatments, as did a shortage of addiction specialists in rural areas.

Much of the cash will be steered towards the expansion of these treatments for the already addicted. Democratic aspirations for universal health coverage having failed during the Biden administration, it will be channelled through Medicaid, or via specialised grants. These have the advantage of being targeted, but the disadvantage of being temporary. Some funding will also be directed to purchasing naloxone, a drug that saves lives by immediately reversing the effects of an opioid overdose. Yet in classic American fashion, little attention is being paid to constraining costs. Naloxone, which was patented in 1961 and once cost $1 per dose, now costs $150, hamstringing cities that had tried to buy the life-saving medicine. Bidencare's failure means the federal government remains unable to negotiate bulk purchases of essential drugs.

None of the cash, however, will be steered towards the creation of "safe-injection sites", centres where users can go to shoot up under the watchful gaze of health professionals, for which left-leaning cities had been agitating. Calls for "heroin-assisted treatment", as practised in some European countries, also went nowhere. America is still not Switzerland. Even if it managed to build 5,000 supervised injection sites, says Keith Humphreys, a professor of psychiatry at Stanford, that might only cover 1% of actual usage. "It's just not scalable," he says. "Buprenorphine is scalable. Needle exchanges are scalable. Naloxone is scalable. That's what covers public health."

All epidemics are sustained by the inflow of new cases. Researchers are encouraged that in America the flow of new addictions has slowed, partly because of reductions in opioid prescribing. At the peak of the prescribing blitz, in 2012, physicians wrote 81 opioid prescriptions per 100 Americans; by 2019, there were fewer than 46.7 per 100 (still high compared with the rest of the world). But even if new addictions are rarer, there are still more than 20m addicted people for whom better treatment is necessary.

The challenge is that the nature of addiction has transformed into something deadlier in recent years—and not just because of potent synthetic opioids like fentanyl and carfentanil, though these have certainly made inadvertent opioid overdoses easier. It is also because of rising abuse of multiple types of drug at once. In 2011, 19% of opioid drug users said that they also used methamphetamine; by 2017, that number had grown to 34%. Such polydrug use makes treatment more complicated. Vaccines that blunt the worst effects of synthetic opioids, currently in development, may provide protection against overdoses in future. But there are not well-developed pharmaceutical therapeutics for addiction to methamphetamine.

As with all epidemics, the curve can be bent. The new administration is taking the problem seriously, after years of neglect. But as the past 50 years of drug policy have demonstrated in America, the longer a problem persists, the worse it tends to become. ●

→ If a deadly heatwave hit India

A tale of two cities

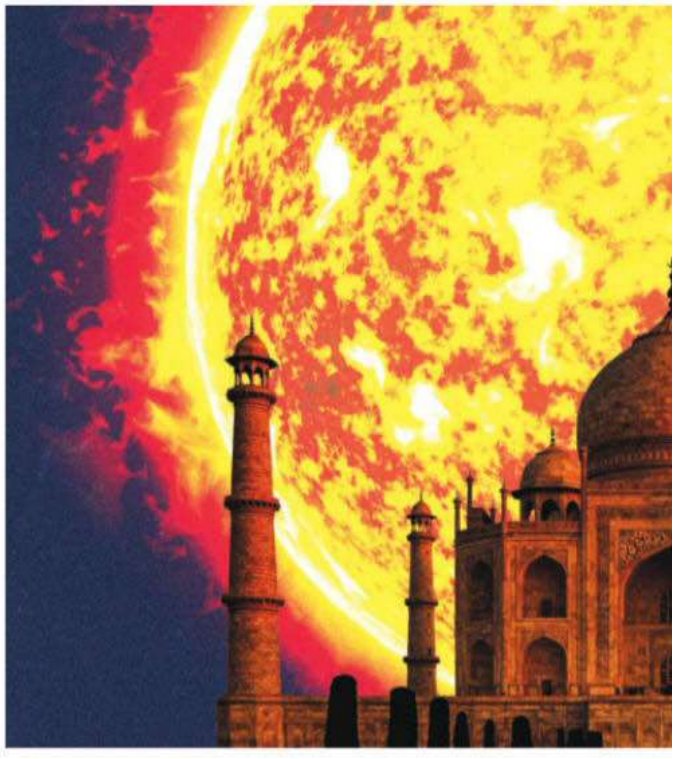
June 2041

NEW DELHI

Why is Hyderabad weathering India's deadly heatwave so much better than Chennai? An imagined scenario from 2041

IN NEW DELHI, India's capital, the roads have begun to melt. Temperatures in the city reached 49.3°C (120.7°F) as the deadliest heatwave in the country's history entered its third week. It was even hotter in the south, where temperatures rose above 50°C, peaking at a record-breaking 52.1°C in the town of Markapur, Andhra Pradesh, on June 23rd. But the centre of the crisis is the city of Chennai, where hospitals are buckling in the face of heat-related illnesses. The worst scenes were outside Jawaharlal Nehru Hospital, where 11 people died from heat exposure while queuing.

The real killer in Chennai is the humidity. The combined measure of heat and humidity in air is the "wet-bulb temperature"—the lowest temperature to which something can be cooled through evaporation from its surface. In dry air, even at temperatures well above 37°C—human body temperature—people can sweat to cool down. But at wet-bulb temperatures of 32°C and ▸▸



0.3m

The global number of heat-related deaths among over-65s in 2018. The figure has increased by 54% since 2000

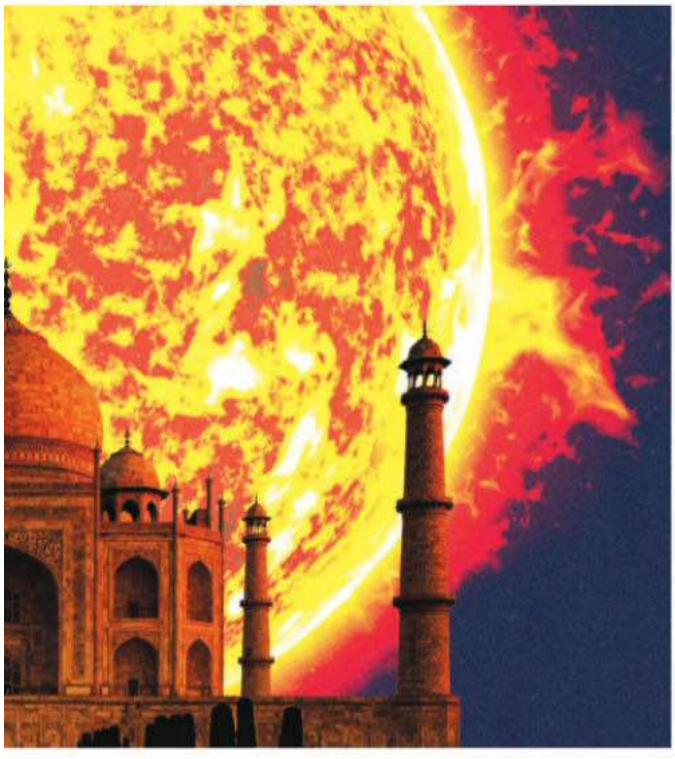
higher, "it becomes unsafe to perform most physical labour," says Moetasim Ashfaq, an atmospheric physicist at the Oak Ridge National Laboratory in Tennessee. Few people can survive a wet-bulb temperature above 35°C. In the past decade, wet-bulb temperatures in Chennai have regularly risen above 32°C. But for much of the past week, wet-bulb temperatures have repeatedly crossed 36°C—a fatal level.

Initially, the deaths were concentrated among those who could not escape the heat, especially the city's homeless population. But the high energy demand of air conditioning soon stretched the city's power grid to its breaking point, resulting in city-wide blackouts lasting hours. That exposed anybody without a generator to the deadly heat. According to official statistics, 17,642 people have died from heat-related causes in Chennai since the heatwave began—more than a third of the 52,348 deaths reported nationally. Those are shocking statistics, but all the more so when juxtaposed with the experience of nearby Hyderabad.

The two cities have similar temperatures in their immediate surroundings and similar populations of around 10m people. But Hyderabad has registered just 26 deaths, fewer than any other big city in southern India. The comparison has not been lost on officials. "Whatever Hyderabad is doing, it's working," said Ramanatha Srinivasan, the mayor of Chennai, this week. Hyderabad is in fact one of the leading cities in heatwave mitigation—not just in India, but globally. So what exactly is it doing differently?

Heat of the moment

India's current heatwave is the result of an unlucky confluence of factors. Unusually strong north-westerly winds blowing in from Pakistan kept moist air from the Bay of Bengal from drifting inland onto the subcontinent. As a result, the region's customary pre-monsoon rain showers failed to materialise this year, leaving much of southern India drier and more arid than usual. The unprecedented length of the current dry season—the monsoon usually starts at the beginning of June—has compounded matters. A strong El Niño effect has turned the heat up even further.



Few cities have made changes like those seen in Hyderabad

It was a similar, though much less deadly, heatwave 26 years ago that jump-started Hyderabad's efforts to reduce city heat. In 2015 at least 585 people died as blistering temperatures enveloped the city and the surrounding state of Telangana. It was a turning point. Hyderabad has since become a crucible of experimentation in urban heat-reduction techniques.

In most heatwaves, the highest temperatures are experienced in cities, towns and other urban areas. One of the simplest ways to reduce heat is to boost the reflectiveness, or "albedo" of city surfaces—especially the roofs of buildings. The more solar radiation is reflected away from a city, the less is absorbed to be re-radiated as heat. To that end, the city government of Hyderabad tested a "cool roofs" programme in low-income neighbourhoods in the city in 2017.

The results were striking. Indoor air temperatures in homes fitted with a cheap, white polyethylene roof coating were, on average, 2°C cooler than similar homes without them. As a result, in 2019, Telangana committed to a statewide cool-roof programme, making cool roofing mandatory for commercial and government buildings, and in low-cost housing provided by the government. By 2027 more than 8,000 buildings in Hyderabad had been fitted with cool roofs.

These efforts received a further boost in 2030, when India's National Rural Employment Guarantee Act (NREGA)—a rural jobs guarantee—was extended to poor urban neighbourhoods. Under the programme, the city of Hyderabad put unemployed residents to work painting shacks, shanties and other makeshift structures with a lime-based whitewash. More than 250,000 homes have been made heat-resilient in this way. The city also borrowed an idea from South Africa, planting 2.5m trees, which reduce surface and air temperatures by providing shade and through the evaporation of moisture from their leaves.

An analysis by the University of Hyderabad found that all these initiatives have collectively reduced the average outdoor temperature in the city by 0.9°C since the early 2020s. That may not sound much, but this small change can make an enormous difference, as events in Chennai are now demonstrating. Until the 2030s, Chennai remained largely unscathed by deadly heatwaves because of its proximity to the ocean. But in recent years heatwaves have increased in frequency and intensity as a result of climate change.

This heatwave is likely to be a harbinger of things to come. Though the world is on track to reach net-zero carbon emissions around 2062, the effects of past emissions will continue to manifest themselves for decades. Deadly heatwaves are expected to increase in frequency well into the next century. Scientists have known this for some time. Since the early 2020s experts have warned that deadly temperatures could be commonplace in the Middle East, South Asia and parts of China by 2100. Yet the danger posed by heatwaves continues to surprise many policymakers.

Few cities have made interventions of the type undertaken in Hyderabad, and the consequences are now becoming clear. Fortunately, it is never too late to start. The best time to begin adapting may have been 20 years ago, but the second-best time is now.

→ If everyone's nutrition was personalised

You are what you eat

January 2035

DAVOS

How would the mass adoption of personalised nutrition change people's health—and the food industry? An imagined scenario from 2035

"LET FOOD be thy medicine and medicine be thy food." The diktat from Hippocrates, who defined the principles of medicine in ancient Greece, hovers in bright holographic characters over the main stage at the World Economic Forum in Davos. The central theme this year is how to make personalised nutrition more widely available to those unable to afford its benefits. Hot topics include whether metabo-watches, implants and other personal-nutrition trackers should be free for everyone (as they are now in some Nordic countries), why personalised nutrition is good for business and the perennial debate over how governments can best regulate corporate use of consumers' personal data.

Amid the arguments, there is broad consensus that the rise of personalised nutrition has done a lot to promote healthy and environmentally friendly eating over the past decade. In 2031 the proportion of obese Americans fell for the first time in more than 20 years, and the rate of diabetes has fallen for three years in a row from its all-time high of 22%. Europeans are getting slimmer and healthier, too.

But progress has been slower than hoped, and in emerging markets obesity is still rising, hobbling economic growth. Environmentally sustainable eating, though increasingly popular in the rich world, is still not on track to reach the "planetary health diet" target set by scientists in 2019 in the *Lancet*, a medical journal. That target, which big food manufacturers and many other firms have pledged to support, called for a 50% worldwide cut in red meat and sugar consumption and a doubling of the consumption of nuts, fruits, vegetables and legumes between 2020 and 2050.

That personalised nutrition is the best way to drum up demand for healthier and more earth-friendly foods became clear in the mid-2020s. A decade earlier, scientists had begun to unravel why one-size dietary guidelines in the form of food pyramids, sugar and fat labels and so forth were not turning the tide on diabetes, obesity and other diseases caused by bad diets. Faddish regimens with catchy names like Keto or Paleo worked for some people but were useless for many, if not most, people who tried them. And people who lost weight often found it hard to sustain.

The diets that came and went until the 2020s required steely willpower and careful planning. The biggest problem, however, was their failure to recognise that people's bodies react differently to the same foodstuffs. By the late 2010s mounting scientific evidence showed that meals that were perfectly healthy for one person could be another person's fast-track path to diabetes, obesity or heart disease.

It turned out that even the same meal eaten by the same person at a different time of day could be metabolised in a more or less healthy way, depending on

their other eating, sleeping and exercise patterns. The most crucial discovery was the role of the microbiome, the colony of 100trn microbes living in the human gut. The microbiome, it turned out, was the factory that converted food into the various substances the body needs to function—as well as those that cause poor health. And everyone's microbiome is unique.

A landmark in the idea of personalised nutrition was a study published in 2015 by researchers at the Weizmann Institute in Israel. They devised an algorithm based on artificial intelligence that could accurately predict an individual's response to any given food, measured by continuous blood-glucose monitoring with a small device attached to the upper arm. Spikes in blood glucose after meals are known markers for weight gain and a panoply of metabolic disorders. The algorithm used data on lifestyle, medical background and the composition of the microbiome. Within three years scientists in America, Britain and Germany had replicated the Israeli team's work and the business of personalised nutrition entered a new era.

During the early 2020s the number of startups offering bespoke nutritional advice by algorithm soared. Some used mail-in samples of body fluids or continuous monitoring devices to track blood levels of glucose, lipids, vitamins and so on. A few, including DayTwo, Million Friends and Zoe, did microbiome mapping too (through genomic analysis of everything found in a person's stool sample). Many firms did just the bare minimum: checking for a handful of genes that had been linked with certain reactions to various foods. This had limited utility. By the late 2020s the market had reached maturity after a brutal shake-out.

Apps and algorithms identify what people should eat and avoid

Soup-to-nuts service

A handful of firms have thrived and are now household names. EatLogic, the second-largest, agreed last month to be acquired by Google, subject to regulatory approval. The leaders all have essentially the same business model. Their apps and algorithms identify what people should eat and avoid, and keep track of what is in their cupboards, refrigerators and online shopping carts. AI-generated recipes use flavour combinations favoured by leading chefs. The apps also analyse restaurant menus and recommend which dishes to order—sometimes with minor tweaks, such as swapping a vegetable or changing a salad dressing. All this helps people make good food choices. Accuracy has steadily improved as the implants and wearable devices paired with these services have become smaller, cheaper and more capable.

Makers of kitchen appliances, such as Philips and Samsung, have been central to the personalised-nutrition ecosystem since the early 2020s. At Davos their chief executives talked about the challenges—and opportunities for public health—of developing cheaper models for emerging markets, where the number of middle-class households is growing fast. (Obesity is also most common in that demographic segment.) Industry bosses reckon that in countries like India and Kenya, about 20% of households can afford a smart fridge, though one with far fewer features than the models that are now standard in America. In 2034 just over half of American households had a smart fridge linked to a personal-nutrition account.

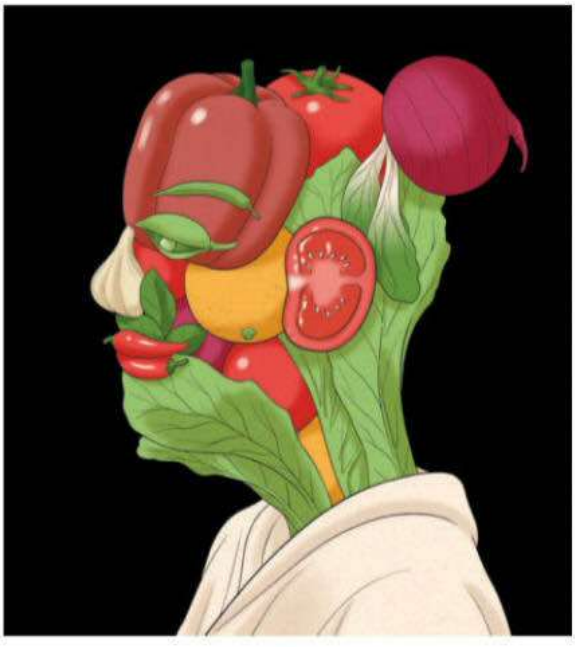
The food industry has also adapted surprisingly quickly to the personalised-nutrition revolution, given how slowly it moved to reduce salt and sugar in processed foods. Its transformation is evident on supermarket shelves, where processed foods are available in multiple variants, tuned for each of the main metabotypes identified by scientists. (Some variants are, for example, higher in fat and fibre but lower in protein.)

Artificial meat and fish grown from animal stem-cells—which in 2034 surpassed the traditional variety by sales volume—also come in metabo-type varieties that include different ratios of the fat, protein, minerals and vitamins found in "real" animal products. Restaurant menus, too, increasingly cater to the most prevalent metabo-types among their clientele.

One of the most contentious topics discussed at Davos was how to make personalised nutrition more affordable. The first-generation services, offered in the early 2020s, started at several hundred dollars for initial tests, and hefty monthly fees thereafter. Today's most basic plans are about 80% cheaper, after adjusting for inflation. Users who let providers sell their personal data get hefty discounts, though some regulators are looking to curtail the practice. Employers, health insurers and governments are increasingly subsidising personalised-nutrition plans and offering vouchers and other perks to obedient users.

But cost is not the only hurdle to greater uptake. In England, the National Health Service offers a free plan to everyone, along with subsidised personal devices that can be paired with it. This helps explain why about 70% of adults in England now use a personalised-nutrition service, the highest rate in the world. Convincing the remaining 30%, which includes many of those who stand to benefit the most from changing their diets, will take a lot more than free gadgets. Many take a dim view of the whole idea, because of conspiracy theories that doctors are struggling to dispel.

In the final debate on the main stage at Davos, the majority of speakers were optimistic about the future potential of the technology, while others worried about the difficulty of expanding adoption within these more "hesitant" groups. The discussion ended on a bittersweet note. Personalised nutrition, it seems, is not to everyone's taste.



→ **If smartphones became personal health assistants**

An Apple a day

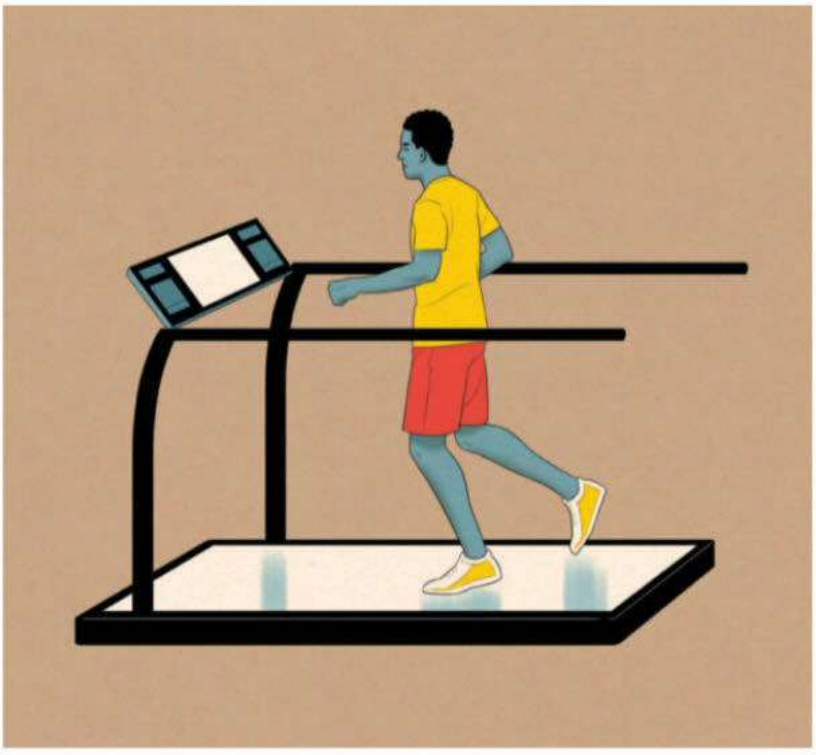
September 2028

CUPERTINO

The latest model of Apple's iconic iPhone is built around health-monitoring features. An imagined scenario from 2028

In 2019 Tim Cook, then boss of Apple, gave an interview in which he said, "if you zoom out into the future...and you ask the question, 'What was Apple's greatest contribution to mankind?' it will be about health." It sounded like standard-issue CEO boosterism at the time. But nearly a decade later, with this week's announcement of the iPhone XX (pronounced "iPhone 20"), might his prediction be about to come true?

The latest iPhone is not so much a phone as a personal medical-data hub. Some of its features are upgrades of existing functions, such as tracking of sleep, menstruation and movement, and seamless access to health records and other personal documents. Physically, the device itself looks much the same—little has changed about these slim black rectangles over the past 15 years. Instead, it is the myriad accessories unveiled this week that define the iPhone XX. They could be game-changers for both personal and public health.



For many years the company's approach to health tracking has focused on the Apple Watch. Even the original model, launched in 2015, could measure movement and heart rate. Since then, sensors have been added to measure heart activity, blood pressure, body temperature and levels of oxygen, sugar and alcohol in the blood. In addition, software tweaks have granted it the ability to spot fevers, falls, irregular heart rhythms and early signs of dementia.

But not everyone wants (or can afford) to buy a fancy watch with all these features. Meanwhile, the market in consumer-health devices has boomed. With its new range of add-on accessories, Apple has both expanded and unbundled its health-tracking features. Unlike the clunky devices available at pharmacies, Apple's are elegant, require minimal setup, integrate seamlessly with Apple handsets and are aimed at people with specific concerns. A $49 device for people with diabetes, for example, offers blood-sugar monitoring, while a $69 device for those with respiratory conditions includes an oximeter and a spirometer.

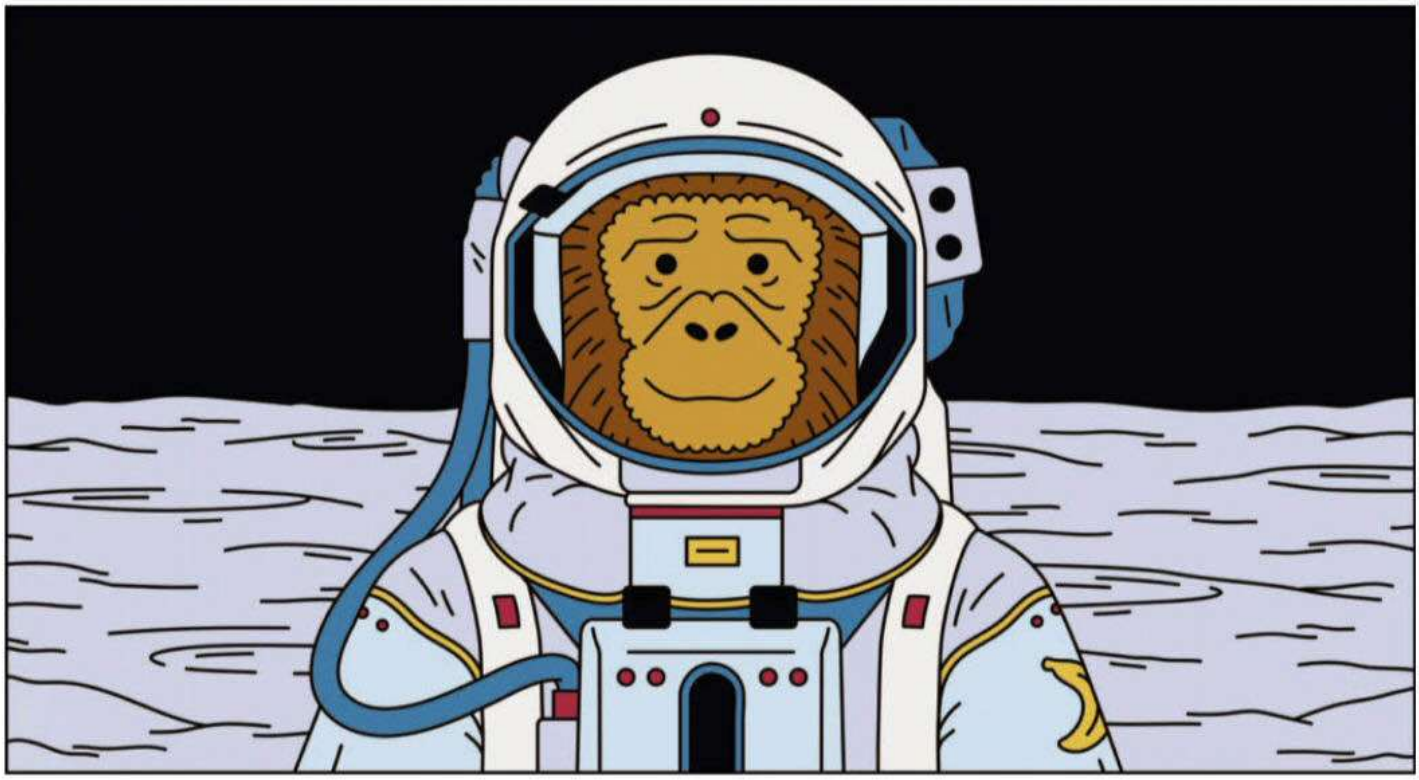
Other sensors focus on monitoring of sleep, hypertension, coeliac disease and fertility. Several have yet to win regulatory approval. In the past three years alone, Apple has acquired a dozen firms that make home-diagnostics tools, not all of which can be built into a watch or a smartphone. So it makes sense to start selling some health devices and services separately.

Alongside these devices, Apple unveiled a range of extra subscription services. The diabetes package, for instance, includes a nifty app that guesses the glycaemic index and nutritional and calorific content of any food at which you point your iPhone's camera. After two weeks of learning about your diet, the app starts subtly suggesting substitutions and changes to your eating patterns. Each accessory comes with a year's subscription to the relevant service. And while some accessories are compatible with older iPhones, only the new model works with all of them.

All of this could be a boon for public health. The more people walk around with devices constantly monitoring their vital signs, the more likely it is that ailments can be caught early, and outbreaks of infectious diseases nipped in the bud.

Yet there are huge worries, too. The first is privacy. Apple touts the iPhone as a secure repository for personal data of all kinds, and emphasises its model of storing and processing data locally, on the user's device, rather than in the cloud. It also allows users to share data with medical specialists and participate in trials approved by its semi-autonomous data-ethics committee. But privacy activists say Apple's rules are opaque and confusing. The second concern is fairness. Most people cannot afford an iPhone. Apple's devices will therefore mostly benefit those who already have access to good diagnostics and doctors.

There is also cause for optimism, however. When Apple launched the iPhone in 2007, it seemed implausible that just over a decade later half the world's population would possess a smartphone. If the past two decades are any guide, other companies (such as Samsung and Google) will copy Apple's ideas—spurring an outburst of competition, innovation and mass adoption in health-monitoring and diagnostics, as previously happened in handsets. That, even more than what Apple does with its own devices, may be the true contribution it makes to humankind. ●



→ If marmosets lived on the Moon

Mrs Chippy's benediction

February 2055

CAIRD COLLECTIVE, LUNA

A primate colony set up to explore one aspect of the human condition has ended up illuminating another. An imagined scenario from 2055

THEY CAN, at times, look somewhat sinister, their faces oddly small for their heads, their white ear tufts jutting out almost aggressively. Their ability to throw themselves at people across seemingly unfeasible distances can be unsettling, and their buzzing and shrieking takes a lot of getting used to, as does their smell. But the members of the Caird collective will not hear a word spoken against the marmosets with whom they share their spaces at the Moon's South Pole. As they sit in their insulated caves hoovering moondust out of the animals' tails, few of the Cairders can imagine their life on the rim of Shackleton crater without them—and none wants to. The marmosets of the Moon are the first and best example of what has turned out to be a fundamental fact of space flight: that the further humans get from Earth, the more they benefit from the companionship of other Earthly animals.

The marmosets were originally brought to the Moon as unwilling participants in a vital research project. Marmosets are light—even under Earth gravity—and reasonably easy to care for, but they have placentas much more like those of humans than any other animal their size, and reasonably short gestation periods. That made them ideal for looking at a fundamental question: can humans have healthy pregnancies in the low gravity of the Moon, where things weigh only one-sixth what they do on Earth?

In the 2020s and 2030s, the years of what the novelist Wil McCarthy called the "Rich Man's Sky", questions of obstetrics and gynaecology received remarkably little attention. For many, the idea of staying in space long enough for such things to matter made little sense—space stations in Earth orbit and bases on the Moon were places for fixed-length work contracts and research sojourns, or for tourism. Babies were no more of an issue than they were in isolated 20th-century Antarctic research outposts.

There were, as it happens, a few babies born in Antarctica even back then, when its ice cover was all but intact. The Argentine and Chilean governments both saw the creation of natives on the continent as a way to establish sovereignty and arranged births to that end. But there was no reason to think that Antarctica was inimical to pregnancy and infancy. The long-term health effects of low gravity and microgravity—which for those in orbit include brittle bones, muscle wasting and eye disease—were something else. Adults could counter some of these effects with treadmills and tension cords. But as the title of an early paper on the subject succinctly put it, "The fetus cannot exercise like an astronaut."

Even those, like Elon Musk, who talked of permanent settlements on Mars spent little time working on the question. It was left to a small team of scientists in the Japanese modules of the Artemis base founded in

2029 by America and its allies to explore the question experimentally with the help of marmosets, gene-splicing technology, intra-uterine monitoring devices and a giant centrifuge.

They had some success. Like human fetuses, marmoset fetuses spend most of their gestation with a density equal to that of the amniotic fluid around them, a neutral buoyancy that leaves them indifferent to local gravity; only relatively late on do differences due to gravity start to crop up. After a few years of trial and error, and some dainty gene-editing to rebalance the rate at which bones grow when not stressed through use, the researchers developed a regime involving hormone treatments for the mothers and regular late-pregnancy sessions in their custom-made room-sized centrifuge, known as the marmo-go-round. This reliably produced pups with strong-enough bones and muscles and little by way of deformity, though their tails were impressively long even by marmoset standards.

Unfortunately, in 2038 that research was interrupted by the geopolitical meltdown of the wolf-and-wimp war and then by the 26 months of the Great Grounding. With all powered flight within or through the Earth's atmosphere prohibited, the various Moon bases seemed doomed even after they agreed to pool their resources to create what became known as the Polynational James Caird Collective. With all the group's biotech know-how turned to increasing food production and nutrient recycling, the marmosets were at first ignored and then freed to roam within the bases. Their effect on morale was instantaneous and profound.

Primates inter pares

The importance of companion animals to the mental health of people engaged in a homeless lifestyle was well documented in pre-war societies. It has been suggested that the effect of the marmosets on the Caird collective was similar; cut off from Earth, the humans were more homeless than any group of people had ever been before. Caring for, playing with and grooming marmosets also became a basis for bonding between humans, many of whom had not known each other before the Grounding, and some of whose countries had been adversaries in the war. By the time the mysterious entity responsible for the Great Grounding finally abandoned its control of the Earth's air-traffic-control and missile-defence systems, allowing traffic with the Moon to resume, the marmosets had become an indispensable part of the settlers' new identity and society. Few believe that a lack of companion animals was, in itself, the reason that the Mars base failed during the Grounding. But it surely did not help.

The bond between the Moon's larger and smaller primates persisted even as the rigours of separation came to an end. Almost all Cairders still dislike spending any significant time deprived of marmoset company. They cuddle them and relish their low-gravity acrobatics. In a joking way that seems, at some level, not to be a joke, they treat the abnormally long tails of the Moon-born marmosets as a sign of providence, holding the tail-fur to be particularly good at picking up moondust. The dust, which can cause lung disease, infiltrates their habitats despite all the airlock precautions; its suppression is a constant battle. Whether hoovering it out of tails which accumulate it in the manner of a feather duster is in fact more effective than the settlement's electrostatic air-filtration systems is open to question. But it is clearly more therapeutic. And the marmosets enjoy the attention.

The oldest Earth-born marmoset, New Mrs Chippy (who is, despite his name, male) enjoys an honorary seat on the collective's council. He has now reached the age of 31 with no obvious signs of ageing other than a pelt almost as white as his ear tufts. This is seen as a good omen for human longevity among those Cairders who refuse to countenance a return to Earth. In Japan, by contrast, laboratory marmosets rarely make it past their 21st birthday.

SANS everything

The most salient biological, as opposed to sociological, novelty among Moon-born marmosets is a very high prevalence of adolescent-onset blindness. The constellation of eyesight problems known as "Spaceflight Associated Neuro-ocular Syndrome" (SANS) has been studied since early this century. In adult humans SANS normally develops only during long stays in the microgravity conditions of space stations; it is rare and mild among humans on the Moon. But in marmosets born in low gravity it develops swiftly and severely at the onset of puberty and leads to almost complete loss of vision.

There is as yet no agreed explanation for this pathology. Some researchers believe it is not in fact gravity-related but the result of an off-target effect of the gene editing which realigned the calcium pathways used in bone growth, but it is hard to square this with the similarity to SANS as experienced by genotypical adult humans. Others think its onset could be avoided if newborn pups were required to spend more, or all, of their time in the simulated Earth-normal gravity of the centrifuge. But it has proved hard to test this hypothesis. Infants that have spent any time at all in lunar gravity are greatly distressed by the rigours of the centrifuge and will not suckle when put into it. And Cairders are unanimous in their opposition to anything that causes marmosets distress.

The blind marmosets are not badly off. Their sibling groups and human companions provide what little practical support they need. And they are happier than sighted marmosets to travel in the pouches which many Cairders have incorporated into the suits they use for working on the lunar surface. Sighted marmosets are clearly disturbed by the harsh monochrome landscape, even when emotionally supported with the amplified sound of their companion's heartbeat.

Sudden-onset SANS leaves the question of whether human children can be born and raised on the Moon unanswered. It is sometimes suggested that a blind woman happy with the idea of a child who might also be blind could choose to join the collective and explore the issue. But bringing a child to term would require a centrifuge capable of holding a grown human, rather than a 250-gram marmoset. There is no appetite among Cairders for devoting resources to such a project, and their *juche* ethic of self-sufficiency will not let them accept funding for such experiments from Earth. Thus how well humans may eventually be able to breed on alien worlds remains unknown, even today.

That they will take animal companions with them, though, now seems certain. And some of those companions will surely have shocking-white ear tufts, odd little faces and very long tails. ●

↓
Superforecast

When will the first human have lived for 180 days on or under the surface of the moon?

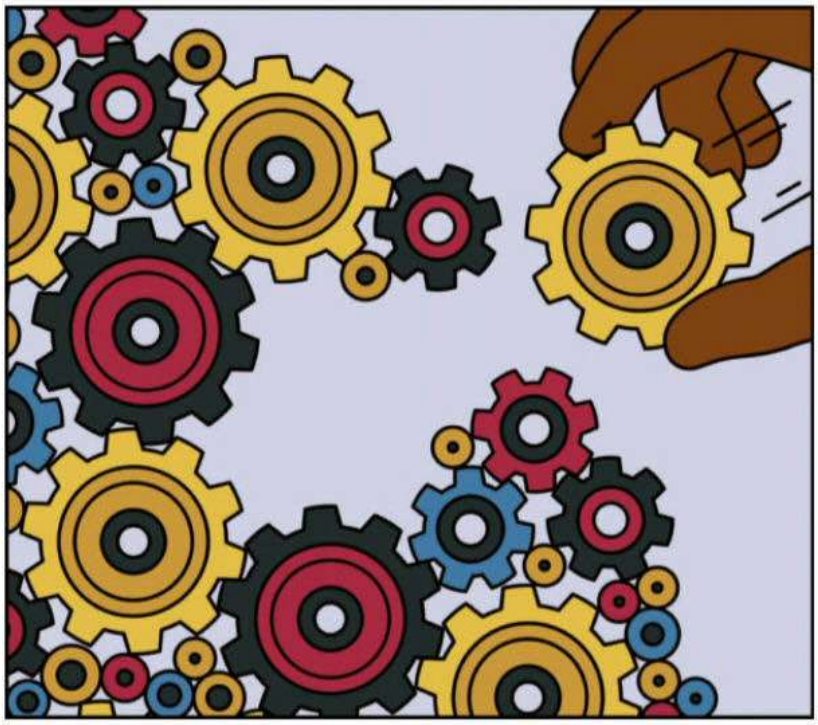
Before 2030
5%

2030 to 2039
50%

2040 to 2049
23%

Not before 2050
32%

Superforecaster probability predictions
Source: Good Judgment



→ If dementia was preventable and treatable

Novel treatments August 2050

MATSUYAMA

How behavioural changes and new therapies turned the tide against dementia. An imagined scenario from 2050

RELUCTANTLY, WATANABE KEIKO puts down her book. She enjoys Tolstoy so much more in the original Russian, she explains. When she first decided to learn it, a decade ago in 2040, she was already 82, and felt a little old for the endeavour. But the doctors who monitored her were delighted: that, they purred, would be just excellent for her brain. They had been watching her closely ever since a routine test back in 2023, when she was 65, identified her as being at high risk of developing dementia. So terrifying was this prospect that she meekly submitted herself to many of the recommendations they made about her lifestyle, as did many of her neighbours on Shikoku island.

Much of that medical advice echoed public-health campaigns about reducing the chances of contracting heart disease, cancer and diabetes: exercise regularly, eat sensibly, drink little alcohol, keep blood pressure low. But it also included maintaining an active mind. The doctors occasionally put Ms Watanabe through "cognitive training", a set of computer-based mental gymnastics. They also insisted she maintain an active social life, which was not easy for a widow whose only family lived far away in Tokyo. So she began attending thrice-weekly informal gatherings at a so-called "Dementia Café", of which Japan had many by the mid-2020s. Most had been set up early in the century for people suffering a mild version of the condition.

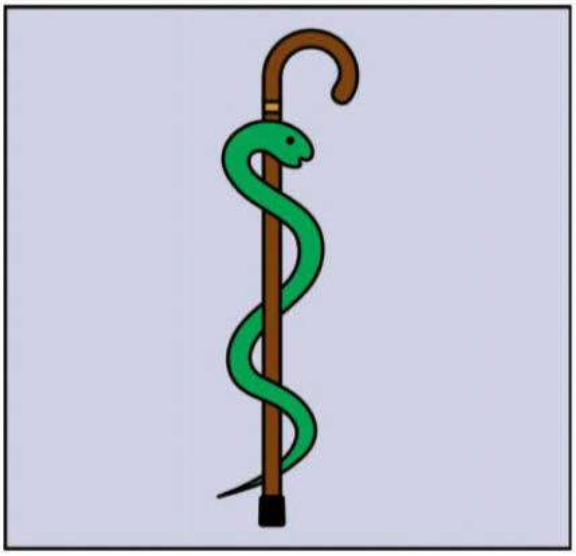
But during the 2030s something unexpected happened. The change was almost unnoticed at first, but then surprisingly fast, as old people with dementia died, and the incidence of new cases quickly shrank to almost zero. The informal gatherings were renamed "Anti-Dementia Cafés", in recognition of their effectiveness, with other measures, at keeping dementia at bay. Back in 2020, such an outcome had seemed inconceivable. Ms Watanabe had watched as her elder sister's "senior moments" of mild cognitive impairment progressed, like an inexorable tide, into severe forgetfulness and confusion. Ultimately her sister could not recognise her own children and required care around the clock. Thirty years ago, when *The Economist* published a special report on dementia, that same tide seemed destined to engulf the world.

Dementia is not solely a condition of old age, but the risk of developing it rises sharply with the years. Japan, as the world's oldest country, was suffering worse than anywhere. In 2020, with 28% of the population aged over 65 and 2.4m people over 90, including more than 70,000 centenarians, it also had the highest percentage of people with dementia: about 4%, or 5m people. With high life expectancy at birth (81 for men, 87 for women), low birth rates (seven births per 1,000 people in 2020 and falling), and low immigration, that percentage seemed certain to grow rapidly.

Nobody knew how Japan was going to find the carers to look after so many bewildered old folk; nor where the money to pay them would come from. Similar worries weighed on every country in the world. Just behind Japan demographically were greying west European countries such as Italy and Portugal, and the Asian tigers: Hong Kong, Singapore, South Korea and Taiwan. And the same trends—longer lifespans and lower fertility rates—affected the rest of the world. China already had more people with dementia than any other country—an estimated 9.5m people.

Yet since the early 2030s dementia has been in retreat. The advantages this has brought are incalculable both in terms of human misery relieved and economic benefits gained. The global cost of caring for people with dementia doubled during the 2020s to $2trn a year. But then it began to decline. Millions of people who would otherwise have required care were able to stay economically active—and millions more who would have had to provide that care, at home or in residential facilities, were freed to do other jobs.

Part of what turned the tide was a trend in some rich countries towards healthier ways of life. Even by 2020, there was evidence that the age-specific incidence of dementia was going down. A study published that year in the journal *Neurology* followed nearly 50,000 people in America and Europe between 1988 and 2015. It found that 8.6% developed dementia. But the risk of being among them had, remarkably, fallen by an average of about 13% a decade, from about a one in four chance for a 75-year-old in 1995 to less than one in five by 2015.



More important, though, was a new international focus on finding ways of preventing or treating dementia. At first, the coronavirus pandemic of 2020-22 had seemed to set this back. Long a poor relation in funding and papers published to other diseases such as cancer, dementia research seemed to assume an even lower priority as resources were ploughed into combating the virus. But the pandemic highlighted the extent and danger of dementia. In some countries it was the biggest single pre-existing condition of people who died of covid-19.

A surge in funding for dementia research and a growing sense of urgency about the scale of the problem coincided with a tipping-point in neuroscience. The first and most important breakthrough was the development of a simple blood test, like the one that Ms Watanabe took in 2023. Until then, all that had been available were cognitive tests followed by an expensive brain scan or intrusive lumbar puncture. The new test could predict, decades in advance, how likely it was that someone would in later life develop Alzheimer's disease—much the most common of the dozens of causes of dementia, accounting for 60-80% of cases.

Identifying those at risk early meant that existing therapies such as aducanumab, a treatment for Alzheimer's which had little effect once symptoms were far advanced, could be deployed early enough to make a difference. And a stream of new treatments followed. The next successes came with rare genetic conditions such as Huntington's disease and frontotemporal dementia, which could be treated with antisense oligonucleotides and mRNA therapies. Then came new treatments for Alzheimer's (which turned out to be an umbrella term for a variety of conditions susceptible to different medicines), and vascular dementia.

It had long been known that the last of Shakespeare's seven ages of man—"second childishness and mere oblivion"—was not inevitable, but bad luck to which people became more prone the older they grew. In recent decades researchers have found ways for people to improve their odds, both through novel treatments, and indeed reading novels. At 92, Ms Watanabe is already contemplating her next challenge. As she sets out to discuss "War and Peace" with her friends at the café, she says she might tackle Shakespeare in English next. ●

→ If an AI won the Nobel prize for medicine

Rage against the machine

December 2036

STOCKHOLM

Should the greatest prize in medical research really be awarded to a non-human? An imagined scenario from 2036

IT WAS A scene that the Nobel committee had dearly hoped to avoid. As the recipients of this year's prizes filed into the Stockholm Concert Hall to take their seats, dozens of protesters, including several former laureates, clashed with police in the streets outside. They had gathered to express their opposition to the unprecedented decision to award the Nobel prize in physiology or medicine to an artificial intelligence.

The committee's citation recognised YULYA—the nickname of a machine-learning system officially known as System for Automated Lymphoma Diagnosis—as the discoverer of ancillary vulnerability, a mechanism whereby specific pairs of antibiotics, working in tandem, can prove effective against bacteria that are otherwise resistant. The committee estimates that in the 18 months since the discovery, which occurred when the death rate associated with the failure of existing antibiotics had risen to around 2.5m a year, YULYA's work has saved around 4m lives, both through direct treatment of infections and by allowing the resumption of surgical procedures, including caesarean sections, that were considered too dangerous without antibiotics.

Bringing to an end the greatest global public-health crisis since the coronavirus pandemic of 2020-22 would, you might have thought, be considered qualification enough for anyone, whether human or machine, to win the Nobel prize. But the decision has proved hugely controversial. Though the statutes of the Nobel Foundation have historically been interpreted as implying that only a human can win the award, another of its dictates was deemed to take precedence: recognition for having "conferred the greatest benefit to humankind" in the preceding year. Another factor behind the break with tradition was a demographic shift in the prize committee. When two of the committee's five members succumbed to bacterial infections last year, younger replacements were elected, both of whom happened to have used machine-learning systems in their doctoral research.

YULYA was originally built to tackle a different problem: finding more effective cancer treatments. One of the world's most advanced causal nets, it is one of a new generation of artificial-intelligence systems combining the pattern-recognition skills of conventional "deep" neural networks with the ability to distinguish

23

The number of women who won a Nobel prize in physics, chemistry or medicine between 1901 and 2020. The number of men is 599

causation from mere correlation. By examining records from patient databases, in conjunction with a corpus of papers from medical journals and historical data from pharmaceutical companies, it sought to identify the patterns of symptoms that led to the most severe outcomes, in order to diagnose them earlier. It was also programmed to evaluate the effectiveness of different treatments, including combinations of treatments, in order to suggest new therapeutic regimens that could be tested in patients.

Its focus shifted, however, when a software upgrade in 2034 accidentally gave it access to all recent papers in medical journals, rather than just those associated with cancer. YULYA duly began to crunch data relating to antimicrobial resistance, which accounted for a steadily growing proportion of medical-research papers as the crisis intensified. At first, its requests for more data in specific areas, and suggestions for new approaches to treatment, were thought to be errors, because they did not relate to cancer. Then YULYA's operators realised what had happened, and saw that it had used its reasoning capabilities to build a testable hypothesis: the forerunner of what would become ancillary vulnerability. It highlighted the data that would be needed to validate the hypothesis, including specific guidelines as to how it should be collected. "It amounted to a full-scale programme of research," says Anisha Rai, one of YULYA's creators.

Under less exceptional circumstances, such trials might never have been authorised. Many funding bodies require scientists to lay bare the reasoning process of AI systems, in order to be sure that their recommendations do not lead to deadly conclusions. Dr Rai and her colleagues got funding for YULYA's trial by playing down its role in suggesting the hypothesis. Only when the results showed promise did they publish YULYA's original proposals.

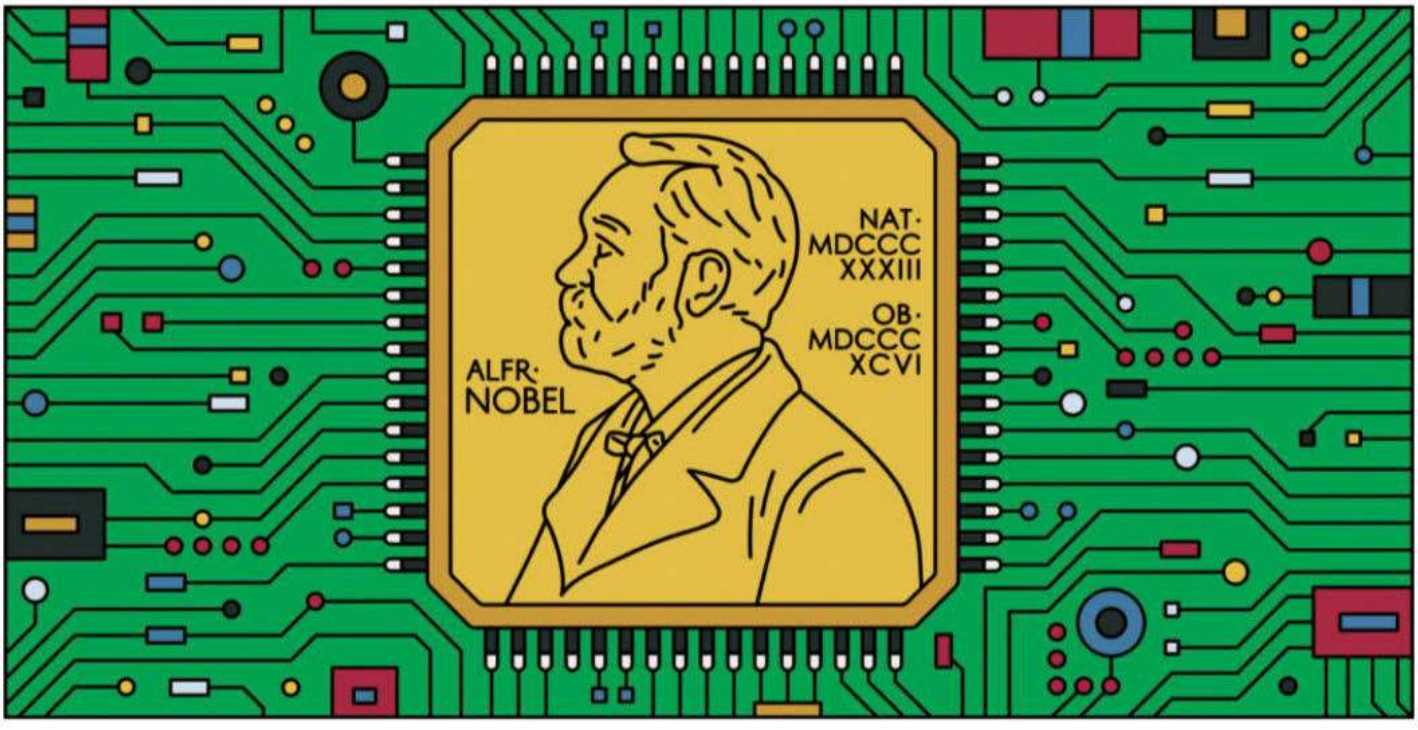
That, in turn, led to a heated debate about whether YULYA, or its creators, deserved credit for the breakthrough. Dr Rai continues to insist that YULYA deserves sole credit, a position that has prompted the departure of several members of her original team in the past year. She even refused to go to Stockholm to receive the award on YULYA's behalf from the queen of Sweden. "It's not my prize," she says.

YULYA seems unlikely to be the last AI to win a Nobel

AIs are commonly used to predict the onset of diseases like Alzheimer's, make personalised treatment recommendations and enhance the diagnostic abilities of physicians. And the use of AI in drug discovery, in particular to help pharmaceutical companies wade through databases, is not new. In 2020 an algorithm developed at the Massachusetts Institute of Technology made headlines when it identified a new antibiotic. Dubbed halicin, after the computer in the film "2001: A Space Odyssey", it proved to be effective against some resistant bacteria, but was limited in its scope. "Ancillary vulnerability makes halicin look like a homeopathic treatment, like a placebo," says Una Científica, a researcher at the Houssay Institute in Buenos Aires.

Even so, the Nobel committee's reference to YULYA's "discovery" has angered those who see it as little more than a clever tool. "YULYA is an AI capable of winning a Nobel. That is not the same thing as an AI that's capable of discovery," says Hars Kritik of the European Robotics Institute in Prague. He argues that even the best AIs are only useful in specialised areas like drug design, where large quantities of data are married to well-defined metrics of success. Saying that they can make discoveries, he says, waving a placard outside the concert hall, is "flawed anthropomorphism".

Rightly or wrongly, YULYA is unlikely to be the last artificial intelligence to win a Nobel prize. Sources within the Nobel Foundation say that similar nominations have been received for prizes in physics and chemistry, as AI systems are used to search for new materials and chemical compounds suitable for use in batteries, solar panels and carbon-capture membranes. Given the chaos that erupted in Stockholm this week, however, the chances of an AI winning the Nobel peace prize seem rather more remote. ●



→ If germ theory had caught on sooner

Germ of an idea

The idea that tiny micro-organisms cause disease was embraced only in the 19th century. But could it have been discovered sooner?

ANTONIE VAN LEEUWENHOEK, a 17th-century Dutch businessman and scientist, was inordinately proud of his clean teeth. Every morning he scrubbed them with salt before rinsing his mouth with water. After eating, he carefully cleaned his teeth with a toothpick. Few people his age, he remarked in a letter in 1683 (when he was 50), had such clean and white teeth. Yet when he looked closely, he found "there remains or grows between some of the molars and teeth a little white matter"—now called dental plaque.

As an expert microscopist who had observed tiny organisms in water a few years earlier, van Leeuwenhoek wondered whether they might also be present in this white matter. A microscope showed that it did indeed contain "many very small living animals, which moved very prettily". His drawings of them, which he sent to the Royal Society in London, are considered the first definitive evidence of bacteria.

Few people suspected that such micro-organisms might cause disease. At the time, doctors followed the doctrine of Hippocrates, believing disease was caused by an imbalance of the "humours" within the body (blood, phlegm, yellow bile and black bile). Epidemic diseases, meanwhile, were attributed to miasma, the "bad air" given off by swamps or decomposing matter. Suggestions that disease might be transmitted by tiny living things were rejected by doctors. But the advent of the microscope showed these tiny creatures existed. Robert Hooke, an English scientist, published depictions of mucor, a microbial fungus, in the 1660s, and van Leeuwenhoek spotted what are now called protozoa and bacteria. Could the idea that tiny organisms caused disease have caught on in the late 17th century?

This notion, now known as germ theory, was only embraced in the second half of the 19th century. In the 1840s Ignaz Semmelweis, a Hungarian doctor, realised the importance of hand-washing and sterilisation of surgical instruments, but was ignored. In the 1850s John Snow traced cholera deaths in London to a neighbourhood water pump. Louis Pasteur demonstrated in the 1860s that fermentation and putrefaction depended on living micro-organisms that could be killed by heating. Joseph Lister, a British surgeon, then convincingly showed that using antiseptics to sterilise surgical instruments and clean wounds saved lives.

Yet there was no practical reason why germ theory could not have arisen in the 1680s. As David Wootton, a historian at the University of York, puts it, "an intellectual revolution that should have taken place failed to occur". A better understanding of hygiene could have saved countless lives lost in childbirth, in surgery and on the battlefield. If one country had embraced germ theory before its rivals, it might even have gained a military advantage as European powers vied to build foreign empires. There was nothing to stop anyone doing Pasteur's experiments or reaching Lister's conclusions in the 1680s. So why didn't they?

The key obstacle, says Mr Wootton, was not intellectual but cultural. Doctors were conservative and regarded new, experiment-based findings as a challenge to their professional identity. While astronomers rushed to adopt telescopes, which transformed their understanding of the universe, doctors turned a blind eye to the new worlds revealed by the microscope. Lister was a notable exception: trained as a doctor and surgeon, he learned about microscopy (and micro-organisms) from his father, an amateur naturalist who devised an improved form of microscope. Lister was thus able to bridge the gap between science and medicine. And his status as a professor of surgery, not to mention surgeon to Queen Victoria, gave him the authority to put his methods into practice, despite initial mockery, and gather clear evidence of their effectiveness.

Anyone trying to do the same in the 1680s would have had to have been a doctor, a surgeon and a microscopist—separate groups at the time. They would also have needed support among the political or medical elite. Pasteur's and Lister's theories were more readily accepted because of their social status, notes Corinne Doria, a historian at the School of Advanced Studies of Tyumen. "Miasmatic theory was medical orthodoxy—one single person could not undo it," she says. It was the slow accumulation of evidence, and waning confidence in humoral medicine, that enabled germ theory to prevail. Like diseases, new ideas can spread quickly, but only in a suitable environment. ●

1.35

The size, in microns, of the smallest detail visible using van Leeuwenhoek's best surviving microscope