‘Connected’ and High-Tech: Your Medical Future

THINK OF IT: EVER PRESENT, ANALYTICS-ENABLED, INDIVIDUALIZED ATTENTION TO YOUR WELL-BEING, WITH A FOCUS ON PREVENTION.

BY **DANIEL KRAFT**

I WOULD NEVER have met Harriett were it not for our mutual friend, Linda. I’m a physician in Northern California; Harriett’s a communications executive in New York City. Linda co-founded an online personal genomics company, to which Harriett and I each sent our genetic information for analysis.

Linda introduced us after she saw that Harriett and I had something in common: a rare type of mitochondrial DNA, which meant we were distantly related. It turns out that we also share that genealogy with a prehistoric celebrity: Ötzi the Iceman, whose 5,300-year-old frozen corpse was discovered in the Alps in 1991. For fun, I even started a Facebook group for people with the same DNA variant as Ötzi and Harriett and me.

I tell this story to make a point. Harriett and I met over a feat of biomedical science—mass-market, low-cost gene analysis—that once was unimaginable and now is commonplace. The convergence of digital

ON PAGE 24

Blink and There'll Be a Bionic Eye

Building a bionic eye has many challenges, but researchers may have just solved one of them: Using 3D technology, they printed an array of light receptors on a glass eye-shaped object. The silver particles they used as "ink" stayed put, despite the curved surface, and the photodiodes converted light into electricity with 25 percent efficiency. Next step: More light receptors and a softer surface to make the implant more comfortable. –RACHEL HARTIGAN SHEA

technologies and social platforms made it possible for us to learn our genotypes and share what we found out with the online universe.

Since then, we've seen an explosion of tech-driven gains and innovations that have the potential to reshape many aspects of health and medicine. All around us, technologies from artificial intelligence (AI) to personal genomics and robotics are advancing exponentially, giving form to the future of medicine.

The innovations I describe here—many of which are still in early stages—are impressive in their own right. But I also appreciate them for enabling the shift away from our traditional compartmentalized health care toward a model of "connected health." We have the opportunity now to connect the dots—to move beyond institutions delivering episodic and reactive care, primarily after disease has developed, into an era of continuous and proactive care designed to get ahead of disease. Think of it: ever present, analytics-enabled, real-time, individualized attention to our health and well-being. Not just to treat disease, but increasingly, to prevent it.

INFORMATION

An Explosion of Health Data

Just how fast is the growth of health-related data? A report from the Stanford University School of Medicine put it this way: "The sheer volume of health care data is growing at an astronomical rate: 153 exabytes (one exabyte = one billion gigabytes) were produced in 2013 and an estimated 2,314 exabytes will be produced in 2020, translating to an overall rate of increase [of] at least 48 percent annually."

IN THE OLD MODEL OF MEDICINE, patients' health data was collected only intermittently, primarily in clinic visits, and scattered among paper files and siloed electronic medical record systems. Today there's a far better option: personal technology that can monitor vital signs continuously and record health data comprehensively.

Just a decade after the first Fitbit launched the "wearables" revolution, health tracking devices are ubiquitous. Most are used to measure and document fitness activities. In the future these sensing technologies will be central to disease prevention, diagnosis, and therapy. They'll measure health objectively, detect changes that may indicate a developing condition, and relay patients' data to their clinicians.

NANOSCIENCE

Useful DNA Origami

Bioengineers have made nanoscale tetrahedrons, bunnies, and more by folding DNA into origami. They enter the desired shape into an algorithm that determines how to bend a long DNA strand, or scaffold, into two- and three-dimensional shapes held together by shorter DNA pieces. Other molecules studded along the scaffold's surface give it its function, like ferrying medicine or gene editing tools to a particular part of the body. MIT's Mark Bathe says the "holy grail" of DNA origami would be a structure that can cross the blood-brain barrier that now keeps many drugs from reaching the brain. –THERESA MACHEMER

PHOTOS, FROM TOP: REBECCA HALE, NGM STAFF; ERIK BENSON AND BJÖRN HÖGBERG, KAROLINSKA INSTITUTET

LENS TEST

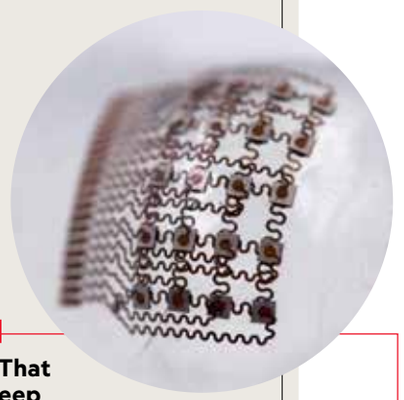
Keeping an Eye on Health

Forget the finger-prick blood test. The race is on to create contact lenses that track glucose levels from tears. South Korean researchers have been able to attach transparent, flexible electronics that won't block vision while wirelessly relaying electricity to run glucose sensors. –EVE CONANT

GASTRO ORIGAMI

Robot Unfolds, Goes to Work

A new wrinkle in origami robots is rectangular, packs a tiny magnet, and folds accordion-style to fit in a pill-size case perfect for swallowing. Now in testing, the robot unfurls in the gut to grab and remove an ingested button battery or patch tissue harmed by its presence. –LORI CUTHBERT



WEAR IT

A Patch That Reads Deep

This wearable patch, smaller than a postage stamp, keeps the beat—heartbeat, that is. It measures blood pressure deep within the body by emitting ultrasonic waves that pierce the skin and bounce off tissues and blood, feeding data back to a laptop. –EC

Flexible, electronic medical tattoos and stick-on sensors can take an electrocardiogram, measure respiratory rate, check blood sugar, and transmit results seamlessly via Bluetooth. It's mobile vital sign tracking, but at a level once found only in an intensive care unit.

Hearing aids or earbuds with embedded sensors will not only amplify sound but also track heart rate and movement. Such smart earpieces also could be integrated with a digital coach to cheer on a runner, or a guide to lend assistance to dementia patients.

Smart contact lenses in the future will be packed with thousands of biosensors, and engineered to pick up early indicators of cancer and other conditions. Lenses now in development may someday measure blood sugar values in tears, to help diabetics manage diet and medications.

Implantable devices may include a radio-frequency ID chip under the skin that holds a patient's medical records, or a subcutaneous sensor that could continuously monitor blood chemistry. Ingestible devices in capsules will deploy once swallowed to perform tasks in the gastrointestinal system, from delivering treatment to isolating foreign objects.

A monitoring patch on a pregnant woman's belly can detect uterine muscle movement, the better to know when labor is progressing. Later, parents can keep a digital eye on their infant via a baby cam that charts the infant's respiration on the screen and sends an alert if the baby stops breathing. There's even high-tech help for developing preemies: headphones play music calibrated to soothe or stimulate, and scans check brain waves to see whether it's working.

And if we want to collect health data when no one's wearing a device? Engineers at MIT have modified a WiFi-like box so it can capture vital signs and sleep patterns of several people in the same residence.

As new sensing technologies emerge, they'll yield more biomedical data and insights—and these can be paired with growing stores of genomic data. In combination, they'll lead us to new ways to optimize wellness, understand disease, and select the most patient-specific preventives and interventions.

THE WIDENING ARRAY of digital tools paired with AI analytics almost certainly will boost diagnosticians' accuracy and speed, improving disease detection at early stages and thus raising the odds of successful treatment or cure. Many likely will be phone-based.

With smartphone otoscopes, parents can look in kids' ears and share the view with a pediatrician. Apps and sensors can enable a phone to take electrocardiograms to check for dangerous arrhythmias; software and a microphone can equip it to "listen" to a cough and diagnose pneumonia. To improve treatment of hypertension—a leading risk factor associated with early death—sensors now in development would take continuous blood pressure readings (no cuff needed).

Some technologies dramatically enhance the accuracy and speed of clinicians' efforts. Identifying a

PHOTOS, FROM TOP: KIM KYOUNG CHAE, UNIST; JASON DORFMAN, MIT CSAIL; CHONGHE WANG AND SHENG XU, UC SAN DIEGO

POSTNATAL CARE

A MUSICAL MILESTONE

BABIES BORN PREMATURELY CAN SUFFER MULTIPLE SETBACKS. A PIONEERING MUSIC PROJECT MAY HELP THEM FLOURISH.

In most nations, premature births—at or before 37 weeks—have risen in the past 20 years. Leaving the nourishing confines of the womb too early can result in complications and often leads to a stay in a hospital's neonatal intensive care unit (NICU).

At University Hospital in Geneva, Switzerland, music is folded into the care plan for some preemies. But unlike other NICU music programs, this novel project features three specific songs, which babies listen to through special headphones made for tiny, fragile heads. The songs are part of an ongoing study that aims to understand how music affects a preterm newborn's brain and how well it can recognize melody, tempo, and pitch—skills likely related to language processing.

Developed by neonatologist Petra Huppi, researcher Manuela Filippa, and composer Andreas Vollenweider, the project involves scanning babies' brains via MRI as they listen and comparing the scans to those of babies who were not exposed to the music. The songs—short and "much simpler than Mozart," says Huppi—were composed to help the infants fall asleep, wake up, or interact.

Further research will assess the full benefit of this therapy, but early findings are promising. MRI scans reveal improved brain connectivity, and the songs appear to support the daily rhythm of sleeping and waking—key to thriving in a noisy NICU and the world beyond. –CATHERINE ZUCKERMAN

PHOTO: CRAIG CUTLER

'ELECTROCEUTICALS'

Power Therapy for the Brain

The use of electricity as medicine has come far since the first cardiac pacemaker. Implanted electrodes, visible in this x-ray, deliver electric pulses known as deep brain stimulation (DBS). These "brain pacemakers" have effectively treated conditions including obsessive-compulsive disorder and Parkinson's disease and are being tested in Alzheimer's patients to improve focus, memory, and judgment. A Cleveland Clinic study of DBS to spur stroke recovery has shown promising results. A 2015 stroke robbed a patient of function on her left side—but after months of physical and occupational therapy and DBS, she plays catch with her grandkids and even threw the opening pitch at a Cleveland Indians game. –PATRICIA EDMONDS

bacterial or viral infection, and the best drugs to treat it, can mean long waits for blood cultures. But scientists have developed biochips that can do a complete microbial scan in a couple of hours, without culturing—and in the process may identify mutations that make some microbes antibiotic resistant.

The boom in research into the human microbiome—the trillions of bacteria on and in each individual's body—is encouraging new modes of diagnosis and increasing understanding. Genetic analysis could help unlock the many secrets of the gut microbiome, believed to play a role in the risk and development of obesity, inflammatory bowel disease, cardiovascular disease, and even neurologic conditions.

Thanks to artificial intelligence and machine learning, diagnostic tools can be trained to read tissue samples and radiologic scans. Google researchers fed more than a quarter-million patients' retinal scans into algorithms that recognize patterns—and the technology "learned" to spot which patterns predict a patient has high blood pressure or is at increased risk for heart attack or stroke. In some comparisons, digital tools produced more accurate analyses than did human pathologists, dermatologists, or radiologists.

IN THE UNITED STATES, the days of doctors routinely making house calls are long gone. Soon to follow: the practice of most medical care occurring in person in a practitioner's office, a clinic, or a hospital. Increasingly, care will be delivered in a blended, real-world-mixed-with-virtual-world model.

The majority of patient-doctor interactions don't require the "laying on of hands," or a physical exam. Private (and increasingly reimbursable) Skype-like interactions between patient and physician will take

SELFIE DIAGNOSTICS

Reading the Whites of Our Eyes

A smartphone app in development at the University of Washington could help diagnose pancreatic cancer by checking the whites of the eyes for signs of jaundice. Snap a selfie and the app would use it to spot elevated bilirubin levels, a possible sign of the disease. –LC

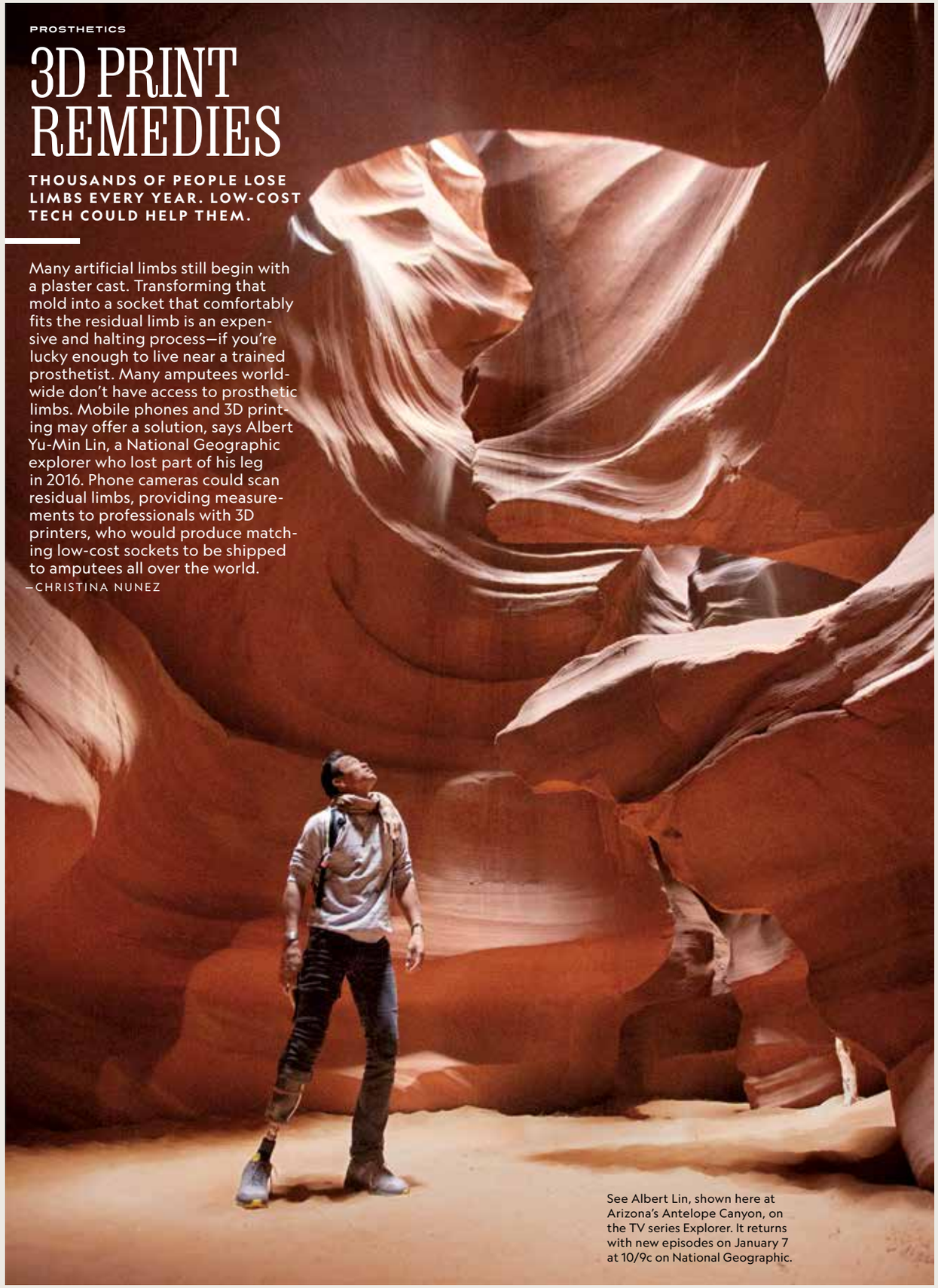
PHOTOS, FROM TOP: OHIO STATE UNIVERSITY WEXNER MEDICAL CENTER; REBECCA HALE, NGM STAFF

PROSTHETICS

3D PRINT REMEDIES

THOUSANDS OF PEOPLE LOSE LIMBS EVERY YEAR. LOW-COST TECH COULD HELP THEM.

Many artificial limbs still begin with a plaster cast. Transforming that mold into a socket that comfortably fits the residual limb is an expensive and halting process—if you're lucky enough to live near a trained prosthetist. Many amputees worldwide don't have access to prosthetic limbs. Mobile phones and 3D printing may offer a solution, says Albert Yu-Min Lin, a National Geographic explorer who lost part of his leg in 2016. Phone cameras could scan residual limbs, providing measurements to professionals with 3D printers, who would produce matching low-cost sockets to be shipped to amputees all over the world.
–CHRISTINA NUNEZ



See Albert Lin, shown here at Arizona's Antelope Canyon, on the TV series Explorer. It returns with new episodes on January 7 at 10/9c on National Geographic.

PHOTO: BRUNA BORTOLATO

THE PRESCRIPTIONS IN YOUR FUTURE COULD BE DOLED OUT BY AN ATM-LIKE ROBOT, REMOTELY CONTROLLED BY A PROVIDER OR ALGORITHM TO ENSURE THE RIGHT DOSES AT THE RIGHT TIMES.

place through web-based portals. Patients' vital signs will be obtained and shared with the physician via web-integrated wireless scales, blood pressure cuffs, and monitoring devices. A telemedicine dermatologist can use the selfie you've sent to prescreen your suspicious-looking skin spot and tell you either to rest easy or get it checked in person.

The time it usually takes for medical appointments—including travel and waiting room time—will plummet, supplanted by telemedicine visits with a new type of clinician, the "virtualist." The provider-patient relationship will take a déjà vu turn, with patients in their own homes for appointments.

In the future your prescriptions may include more "digiceuticals." Already in limited use, they're meant to enhance well-being or manage a condition with no drugs, no in-person ministrations—just use of prescribed software, or digital exchanges with a practitioner offering information and encouragement.

Though many are still under study, some digiceuticals are demonstrating effectiveness. Examples: At least two firms have developed apps to reduce the relentless noise of tinnitus by retraining the brain to turn down the volume—and some reviewers say it works. To manage heart failure patients, the Mayo Clinic prescribed the use of an app that would track blood pressure, activity, and other factors. The reported result: a 40 percent reduction in hospital readmissions related to cardiac issues.

The conventional prescriptions in your future could be doled out by an ATM-like robot, remotely controlled by a provider or algorithm to ensure the right doses at the right times. Or your clinician could consult your genetics test to determine the most appropriate drugs for your specific gene profile.

A few months ago, Harvard and MIT scientists found a way to much more accurately forecast an individual's risk score for five deadly diseases. They achieved this by looking at DNA changes at 6.6 million locations in the human genome and applying a sophisticated algorithm. But even genetic tests that analyze only parts of the genome—like the one I took—can provide valuable information about predisposition to dementia, Parkinson's disease, diabetes, and other conditions. Yet again, advances in medical technology may hold benefits for me, and for Harriett. (Sorry, Ötzi.)

If you're not meeting in person with your practitioner, could a robot serve as well as a human? Soon

AUGMENTED, VIRTUAL REALITY

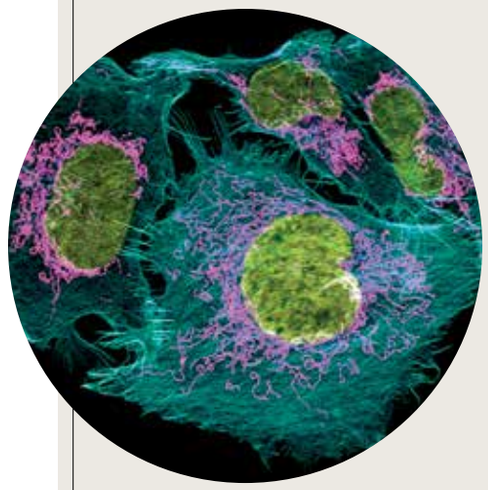
Bending Reality to Medical Uses

Augmented and virtual reality (AR and VR) are moving from the gaming world to the medical school, clinic, and operating room. Nursing and medical students can learn anatomy and physiology on VR tours of human organs. Operations recorded or live-streamed in VR let far-flung students observe from the vantage of surgeons. VR therapy leverages the intense, immersive experience to treat pain, phobias, and other conditions. AR can blend imaging data with actual procedures, so a surgeon at work can see into a body or be guided by a remote mentor. –DK

GENETIC TOOLS

Better Prostate Cancer Analysis

High-grade prostate cancers can be lethal, low-grade cases may need only monitoring—and both may benefit from recent advances at the Cleveland Clinic. One research team found that patients with a testosterone-based genetic anomaly had different responses to certain drugs, which could open the way to personalized treatments. Other researchers developed a new blood test that predicts prostate cancer risk more accurately than existing tests; it could dramatically reduce the need for biopsies and the treatment of cases unlikely to be lethal. –PE



Fluorescence delineates the parts of these prostate cancer cells.

THREE-COLOR CONFOCAL IMAGE: JAMES HAYDEN, WISTAR INSTITUTE

they may be answering information and triage calls. A chatbot nurse will try to learn what ails you by asking about your symptoms and tapping into data from your wearable devices and the crowdsourced health records of others like you. Should your complaint be psychological more than physical, you can seek counseling from a virtual therapist programmed to converse as a human would, offer self-help guidance, and lend a sympathetic ear.

Robots may participate in care during face-to-face encounters as well. Consider the robotic phlebotomist, equipped to ultrasonically confirm which vein is the best target, then draw blood or insert an IV. In countries short on human caregivers, caretaker robots may be employed to lift and move patients, as well as interact socially. And robots programmed as physical therapy coaches can help patients stick with their exercise regimes.

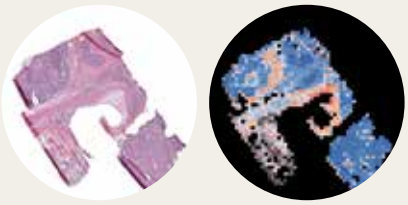
IT'S GREAT TO BENEFIT from all this technological progress, but it's just as important to spread it. In 2016 an estimated 3.6 million people in low- and middle-income countries died because they lacked access to health care. And even more people in those countries—an estimated five million—died because they got poor-quality care. We can change that, starting today, by sharing the wealth of new medical technologies and other health and wellness resources. □

Daniel Kraft is a physician-scientist trained at Stanford and Harvard. He serves as faculty chair for medicine at Singularity University and is founder and chair of Exponential Medicine, a program that explores the convergence of accelerating technologies and their implications for the future of health care.

AI ANALYSIS

The Sharp Eyes of AI

Correctly identifying the cancer cells in a lung tissue sample (below left) is key to successful treatment. It's also an ideal diagnostic use of artificial intelligence. In one study, the same AI that Google uses to identify objects online was trained to recognize forms of cancer. It then found two forms in a tissue sample (below right) as accurately as a human could, in seconds. AI also has been used to model the precise dosage of a cancer drug to shrink tumors but cause minimal toxic side effects. –LC



For the sample at left, AI produced the analysis at right, showing normal lung tissue (gray) and two forms of cancer: adenocarcinoma (red) and squamous cell carcinoma (blue).

REGAINING MOBILITY

Robotic Support

For patients with severe mobility problems such as partial paralysis, scientists are developing robotics that enfold and support like an exoskeleton. The devices are programmed to guide the body through motions—such as helping a stroke victim walk—that can rebuild posture and strength. –NATASHA DALY

FROM TOP, TISSUE IMAGE: CANCER GENOME ATLAS; HEAT MAP: NICOLAS COUDRAY, NYU SCHOOL OF MEDICINE; PHOTO: MARCEL VAN DEN BERGH