Science Fact

Human 2.0: Being All We Can Be Part I

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Many installments in this science-behind-the-fiction series have focused on aliens. Do they even exist? If yes, what might they be like? Will it ever be practical for humans to visit them, or them to visit us? Whether face to face (or whatever), or via comm link, could we and they overcome our doubtless many differences to learn to speak (or whatever) with one another? Might we and they—whether because under the skin (or whatever) we're in some manner too alike, or too different—go to war with one another?

Perhaps it all seemed too speculative. Escapist. Purely SFnal.

It shouldn't.

Soon enough, we humans will share our world with intelligent beings quite unlike human norms. . . .

Because soon enough some of us, or our descendants, will have become them.

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A very early SFnal interest

Tinkering with the nature of humanity goes to the earliest roots of the genre, and the imagined changes were not always for the best. As a representative sample, consider:

- *The Strange Case of Dr. Jekyll and Mr. Hyde* (Robert Louis Stevenson), 1886, can be seen as an early literary exploration of changing—if not necessarily improving—man by chemically separating his baser, animalistic nature.
- Edmund Hamilton's 1931 story "The Man Who Evolved" harnessed concentrated cosmic rays (I *did* say 1931) to jump eons ahead in development. ("As we are to apes, so must the men of the future be to us.")

- Olaf Stapledon's 1935 *Odd John: A Story Between Jest and Earnest* envisions more-than-human beings arising from chance mutation.
- Craig Ellis's "Dr. Varsag's Experiment" (1940) grafted the nervous system of a mongoose into a human, making him one heck of a boxer until unintended consequences kicked in.

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Are recent fictional transformations any more credible than the early batch? If you recall humans evolving gills in *Waterworld* (1995) or the drug mule/heroine of *Lucy* (2014) developing physical and psychical enhancements after her illicit cargo springs a leak, you will have justifiable doubts—but I prefer to believe those movies are outliers. Ditto the man-to-monster genetic transformation by aboriginal soup recipe in Douglas Preston and Lincoln Child's 1996 novel *Relic* (the basis of the 1997 movie, *The Relic*).

In this article, we'll survey emerging technologies that will soon require us to take a fresh look at what it means to be human and a sampling of how SF has incorporated these possibilities.

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Eugenics and the Ubermenschen

Francis Galton, cousin to Charles Darwin and coiner of the term *eugenics,* from the Greek for well-born, suggested improving our species by means of judicious marriages.[1] While Galton sought via "positive eugenics" to reinforce traits he perceived as advantageous, other eugenicists advocated the withdrawal—or involuntary removal—of perceived undesirables from the reproductive population. The English Eugenics Society, founded by Galton, opposed extreme forms of "negative eugenics," but compulsory sterilization of allegedly mentally deficient individuals was once legal in a majority of the states of the United States.[2]

For a time eugenics fell within mainstream thought. Eugenics drew support from, among many, Winston Churchill, Theodore Roosevelt, Herbert Hoover, George Bernard Shaw, H. G. Wells—and, in a far more extreme form, Adolf Hitler.[3] Following Nazi recourse to eugenics to cast Aryans as ubermenschen (supermen) and justify the genocide of the Holocaust, eugenics fell into deep disrepute.

As befitted a scientific topic once hotly debated, genre literature addressed eugenics in a broad range of utopian and dystopian stories—few of them much remembered. One exception is *The Skylark of Space,* arguably the earliest space opera.[4] The *Skylark's* square-jawed, all-American crew, while visiting the extrasolar planet Osmone, accepts with evident sympathy the local culture and religion rooted in Darwinian competition and eugenic breeding. Another notable exception to that selective amnesia is C. L. Kornbluth's bitingly satirical 1951 novella, "The Marching Morons."

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Genetic therapy

Eugenics developed before an understanding of DNA suggested a subtler route to species improvement. In recent decades, molecular biologists have developed the insights and tools with which to selectively alter a life form's genes, both within a species and with contributions from donor species. Genetically modified organisms, such as vitamin-A-producing "golden rice," have become familiar—if still sometimes controversial.[5]

One impetus for genetic-engineering research, not surprisingly, is the perceived opportunity to cure human diseases. Such research can be pharmacologically oriented, as when bacteria are modified into "bioreactors" for the mass production of otherwise conventional therapeutics. In this article, our interest is in another line of investigation, dealing with illnesses that have a genetic component. Simply put, if a problematical gene(s) in our cells can be replaced, then perhaps the associated disease can be cured and even eliminated.

Nature long ago developed the means to insert genes into living cells: with viruses. Cutting-edge medicine uses purposefully modified viruses to deliver therapeutic genes.

One class of treatments involves viruses modified (a) to carry a therapeutic gene and (b) not to replicate themselves. A common delivery vector for these treatments is the adenovirus, which, in its unmodified form, is one cause (among others) of the common cold. Of course viruses sometimes trigger immune responses, our immune system being, after all, in part a defense against viruses. Jesse Gelsinger, treated with an adenovirus-based therapy for a rare genetic liver deficiency, died in 1999 from an immune-response complication. He thus became the first known fatality from gene-therapy research.

A second class of virus-based therapy permanently modifies the patient's cells. Alas, there is nothing simple about getting the desired gene(s) spliced into a suitable chromosomal location(s), in the appropriate quantity, and only within the targeted cell type. *In vivo* gene splicing uses tailored retroviruses to deliver the therapeutic payload, but retroviruses can't (yet) be directed where in our chromosomes to insert the genetically engineered payload.[6]

A random point of gene insertion may go without serious consequences—or it can be a matter of life and death. While scarcely 1% of the human genome codes for protein synthesis, recent studies show that as much as 80% of noncoding DNA performs at least some biochemical function.[7] Thus, a viral vector randomly inserting its therapeutic payload into a patient's chromosome might: impact that cell's ability to synthesize an important protein; turn the cell cancerous; or, at the opposite extreme, interfere with the cell's ability to divide at all. Four of nine patients treated between 1999 and 2002 for "bubble boy disease" (more formally, X-linked severe combined immunodeficiency) developed leukemia as a consequence of their retrovirus-based gene therapy.[8]

But there have also been successes. Genetic engineering may one day offer treatments for such diseases as diabetes, sickle cell anemia, and some cancers. As I type (June 2015), research trials of genetic therapies have involved only small numbers of patients with specific diseases. That said, the first commercial genetically engineered pharmaceutical, to treat a rare condition called lipoprotein lipase deficiency, recently arrived.[9] Big Pharma is ready to dive into the genetic-therapy market.[10]

As research continues into genetic cures, it becomes clear that the technology's prospective uses extend beyond therapy.

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Genetic enhancement

Amytrophic Lateral Sclerosis (ALS), aka Lou Gehrig's disease, destroys the neurons responsible for voluntary muscle control. ALS patients progressively lose control of their bodies, until they are unable to move, trapped within their own bodies. It is a horrible disease.

In researching a possible treatment for ALS, biologists genetically modified healthy mice to increase their production of the hormone Insulin-like Growth Factor 1, IGF–1. These mice ceased to lose muscle mass with age! In related experiments, genetically treated rats showed significant muscle-mass *gain*. Experiments with an IGF–1 variant called MGF showed a 20% muscle-mass gain and a 25% increase in strength—without exercise.[11]

Not surprisingly, perhaps, there appear to be tradeoffs associated with increasing IGF–1 levels. In studies with mice, reduced IGF-1 levels have been associated with, on the one hand, small size, delayed puberty, and reduced fertility and, on the other hand, with increased lifespan and reduced risks of cancer and diabetes. Reduced IGF–1 levels may also improve human longevity.[12] Are there people who would favor increased muscle mass over a longer life? Given the types of bodily injuries many pro athletes willingly risk, I suspect that some people would.

Nor is exercise-free body building the sole enhancement that would seem easy to market widely. Leptin is a hormone whose levels influence appetite and metabolism. How popular might be a gene therapy that combats or prevents obesity?[13] How about a treatment that reactivates hair follicles to reverse baldness?[14] A bit more speculatively, consider a genetic treatment that—without ultraviolet light—produces a skin tan, whether as a permanent change or as activated/deactivated by taking a pill. Would that treatment best be described as a cosmetic procedure (note that cosmetics are a multibillion-dollar business) or as a melanoma preventative?

Pro athletics has been rocked in recent years by doping scandals. That is, some athletes have been caught using performance-enhancing drugs. One of the drugs sometimes (ab)used is erythropoietin, or EPO, a hormone that controls the production of red blood cells. Increase your red-cell count a little and your blood can carry more oxygen, increasing your endurance. But to thicken the blood with extra red cells increases the risk of forming blood clots ("thrombi") in veins and arteries. Such clots can block blood flow to the brain, heart, and lungs, producing, respectively, a stroke, heart attack, and pulmonary embolism. Not to put too fine a point on it, too much EPO can kill.[15]

Our bodies naturally produce EPO; hence, the athletic ban against synthetic EPO initially relied upon intrusive searches (e.g., of physical possessions) rather than on blood tests. Might athletes want a genetic tweak to increase their bodily production of EPO? The temptation will surely be there, especially once EPO-based gene therapies, currently being tested on mice, are approved for the treatment of human anemia.

Of course, we've only scratched the surface of possible genetic tweaks. The more biologists discover, the broader becomes the set of conceivable alterations. Once we become accustomed to genetic therapies, cosmetic treatments, performance enhancements, and (as yet, still speculatively) lifespan extenders, how long will it be until we are ready to consider more radical genetic changes?

Science fiction, of course, has explored many of the possibilities of genetic engineering:

- Nancy Kress's 1991 "Beggars in Spain" examines the consequences of a gene tweak that eliminates the need for sleep and bumps up intelligence. The novella won both the Hugo and Nebula Awards for that year, was developed into a 1993 novel of the same name, and led eventually to the three-book Beggars series.
- In microgravity, hands might seem more useful than feet. Lois McMaster Bujold introduced the genetically engineered, four-armed-and-no-legged quaddies—and a study in morality—in *Falling Free* (first serialized in *Analog,* December 1987–February 1988). This 1988 novel was also a Nebula winner.
- From tattoos to body piercing to facial hair, people have long used bodily modification to express themselves. With gengineering, people may someday make bold personal statements via far more extreme body mods. When life turns monstrous, why not become a monster? So Mike Brotherton had it in his 2003 novel, *Star Dragon*.
- And who can forget the 1982 film *Star Trek II: The Wrath of Khan,* in which Our Heroes battle an exiled race of genetically engineered supermen?

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Artificial organs

Not every disease or injury lends itself to genetic therapy. Regenerative medicine—the growth of replacement organs (e.g., from stem cells)—remains a young technology.[16] Compatible organs aren't always available for transplant when a patient needs them. Another option is artificial organs, and in this section we'll review a few types of them.

Without a functioning heart, we die. Soviet surgeon Vladimir Demikhov experimented with artificial hearts (on animals) as far back as 1937. Research into cardiopulmonary bypass (CPB) machines dates to the 1880s, and CPBs have provided temporary heart and lung function during cardiac surgeries since the 1950s. In 1969, an implantable mechanical heart was first used to support a human patient until a donor heart could be found (although the patient died of infection shortly after the transplant procedure). Modern, implantable artificial hearts like the Jarvik 7 have been used by hundreds of patients as a bridge to transplantation. Short of replacing a failing heart, many cardiac patients have been equipped with an implanted electromechanical "ventricular assist device." Many cardiac patients whose hearts would otherwise beat too slowly have had electronic pacemakers implanted.[17]

Among the functions of kidneys is filtering the blood, then transferring the water-soluble metabolic waste products to the urinary system for removal. Kidney disease degrades this critical function, and sufficiently advanced chronic kidney disease can, at present, be treated only with (hours at a time, at least several days per week) dialysis or by a kidney transplant. An implantable artificial kidney remains the dream of thousands with end stage renal disease (also known as Stage 5 chronic kidney disease) who require dialysis. Medical R & D is not yet there, but a portable/wearable artificial kidney recently began human trials.[18]

Type 1 diabetes mellitus is the condition in which the pancreas fails to synthesize sufficient (or any) insulin, the hormone that regulates the level of glucose in the blood. Too little glucose, and a person faints. Too much glucose and over time, a person suffers damage to nerves and blood vessels. The possible consequences of such damage are many and varied, including blindness (diabetic retinopathy), pain, numbness, nausea, incontinence, kidney disease, heart attacks, and strokes. Infections and ulcers of the foot that go unnoticed due to diabetic neuropathies are a leading cause of lower-limb amputation.

In conventional management of type 1 diabetes—there is no cure—the patient tests his blood sugar several times each day, each test involving a needle stick. He then calculates and injects a dosage of medicinal insulin to reflect his planned exercise and meals. The process is uncomfortable, intrusive, prone to misestimation, and interrupted whenever the patient sleeps.

Enter the artificial pancreas. Such an artificial organ combines a glucose sensor, implantable insulin pump, and personalized control algorithms executing on a microprocessor—which can be a Bluetooth-enabled smart phone. Artificial pancreas devices are already on the market.[19]

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Wearable enhancements

Sound-amplifying devices treat hearing loss. Corrective lenses treat impaired vision. And nothing constrains wearable devices to the limits of our natural senses.

Smart eyewear like Microsoft HoloLens and Google Glass (and already under development: smart contact lenses) enable augmented vision that superimposes over one's view of the real world all manner of information: directions, reminders, lookups (who *is* that passerby who seems so familiar?), fanciful decorations, and, inevitably, advertisements and graffiti. Making use of sensors we wear, perhaps in a wirelessly linked smart watch or activity-tracking wristband, augmented vision can deliver timely health advice. Heartbeat monitors can help us achieve aerobic exercise levels without overdoing it. Sweat sensors can warn us of disease.[20]

Nor need personal biosensors reside in clunky jewelry, with its often-intermittent bodily contact. Smart body decals in field trial (as of May 2015) incorporate many thousands of transistors, resisters, sensors, and other electronic devices. Various "Biostamps" measure body temperature, UV exposure, pulse rate, blood-oxygen levels, and more. When tiny sensors don't exist for key health indicators, clever algorithms in onboard microprocessors can sometimes combine or convert available measurements into a useful surrogate reading. To directly measure blood pressure, for example, involves a bulky compression cuff. As a substitute, Biostamps use pulse readings from nearby sensors to derive pulse-wave velocity, which correlates with blood-pressure changes. Biostamps power themselves with harvested RF energy, such as from the near-field communications (NFC) signal emitted by modern smart phones (for use with wireless payment systems like Apple Pay). Biostamps also use an NFC signal and a tiny onboard antenna to upload their data. Candidate applications of such decal-based smart sensors include:

- monitoring infants in neonatal-care units,
- tailoring personalized skin-care recommendations (L'Oreal is funding that research),
- inferring the stress levels of air-traffic controllers from changes in their skin temperature, and
- measuring electrical activity in the brain for sleep apnea studies with an unobtrusive behind-the-ear skin patch.[21]

Do we and our wearable and/or implanted devices at some point cross a threshold to become cybernetic organisms—cyborgs?

* * *

Prostheses (and other theses)

A prosthesis is a mechanical or electromechanical replacement for a missing body part, whether the need arises from injury or congenital condition. For centuries, hooks and peg legs were state-of-the-art prosthetic devices—hardly technological.

Modern prostheses are far more sophisticated. Some use motors to exert force. Some employ an embedded microprocessor(s) to fine-tune motion. In some artificial knees, for example, microprocessor-enhanced control offers a natural gait by dynamically adjusting joint positioning to the walker's pace. Prostheses that exploit electromyography (the measurement of the electrical activity of muscles) are controlled by voluntary muscle contractions. In some prosthetic arms, gripping systems provide force feedback to the controlling muscles.

Put all those technologies together—and add forty million dollars of R & D—and you get (cue 1980's *The Empire Strikes Back),* the newly FDA-approved "Luke Arm."[22] This sophisticated prosthesis, similar in size and weight to a natural human arm, combines microprocessors, motors, and myoelectric control; it also allows the simultaneous, independent operation of multiple joints (e.g., of individual prosthetic fingers).

My hand, whenever it touches something, signals via my peripheral nervous system more than just the force that I'm exerting. It conveys the temperature and the texture of the object's surface. Without such inputs, I might burn myself on a hot pan or allow a wet glass to slip from my grasp. The next step in prostheses is to enable a broad range of feedback. The Defense Advanced Research Projects Agency (DARPA) recently kicked off the HAPTIX ("Hand Proprioception and Touch Interfaces") program to create a prosthetic hand system that moves and provides sensation similar to a natural hand."[23]

A yet more natural limb replacement would directly accept commands from, and return sensory feedback to, the wearer's nervous system—and the technology for such a prosthesis is within sight. On an experimental basis, a prosthetic neural interface was demonstrated in 2009. With electrodes surgically implanted into his arm stump, an amputee volunteer successfully operated and received sensor feedback from Cyberhand.[24] The body's natural defenses against foreign materials triggers an immune response, and it's difficult to make such implanted electrodes permanent. (And so, in my 2002 novella "Presence of Mind,"[25] rather than implanted electrodes, the neurally interfaced prosthesis contained sensors sensitive enough to remotely read impulses from the truncated nerve branches in the hero's arm stump.)

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Mind over muscle

What about interfacing prostheses directly with the brain, bypassing the peripheral nervous system? There's been progress on that front, too. Brain/machine interfaces (BMIs) are of three types. All involve, in one way or another, sensing the slight voltage changes produced by the operation of the neural circuits of the brain, isolating the neural signal(s) intended for a particular purpose, and repurposing the recovered signal(s) to operate the prosthesis.

The least invasive—and least sensitive—BMI technology uses electroencephalography (EEG), with sensors placed on the scalp. The human brain is comprised of roughly one hundred billion neurons; from outside the skull, EEG "sees" high-level/aggregated neural activity rather than the firing of specific synapses. Despite its limitations, volunteers using an EEG-based BMI have, with training, learned to operate robotic arms using only their thoughts.

The most sensitive BMIs respond to the activity of specific, targeted neurons. These BMIs require opening the skull and implanting electrodes in the brain. Even with brain surgery, inherently invasive and risky, only near-surface neurons are accessible.

A recent, middle-of-the-road BMI technique, electrocorticography (ECoG), drapes a sensor mesh over the cerebral cortex. While this technique still requires opening of the cranium, surgery on the brain itself isn't involved. ECoG BMI remains experimental; the human trials being done are in conjunction with brain surgery required for other, therapeutic reasons.[26, 27]

Limb prostheses have heretofore benefited amputees, but BMI techniques are beginning to extend the utility of prostheses to a whole new population: those who suffer from partial or complete paralysis. Quality of life is surely improved when someone who has lost the ability to feed herself or turn pages of a book can, by the power of her thoughts, direct a robotic arm to do it for her.[28] A paraplegic with a mind-controlled exoskeleton climbed out of his wheelchair to personally kick off the 2014 World Cup.[29]

Mind-controlled robotic systems have been too expensive for widespread deployment. That, too, may be about to change.[30]

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Better, stronger, faster

If technology can replace a body part, can technology at the same time improve upon it? That was the premise of the iconic 1974 television series *Six Million Dollar Man* (based on the 1972 novel *Cyborg* by Martin Caidin). Cyborg Steve Austin had bionic legs, a bionic arm, and a bionic eye.

While technology has yet to match Steve Austin's enhancements, the more-capable-than-human prosthesis is no longer mere theory. In 2007, the International Association of Athletics Federations (IAAF) rewrote its competition rules to ban "any technical device that incorporates springs, wheels, or any other element that provides a user with an advantage over another athlete not using such a device." The next year, the IAAF banned double amputee and paralympian Oscar Pistorius, because his Flex-Foot Cheetah prostheses (aka, "blades") capture and release kinetic energy—like springs. The IAAF reported that, "An athlete using this prosthetic blade has a demonstrable mechanical advantage (more than 30%) when compared to someone not using the blade." The Court of Arbitration for Sport overruled the IAAF, allowing Pistorius to compete in the 2008 Olympics.[31]

Hugh Herr, director of the biomechatronics group within the MIT Media Lab—and a double amputee who walks on prostheses of his own design—predicts that "Fifty years out, I think we will have largely eliminated disability."[32]

As prostheses improve in capability and naturalness, might they seem desirable to some people with unimpaired bodies? To some people with mild or age-related impairments? Rather than retrofit weak, achy, legs with replacement hips and knees, won't some people prefer to replace entire legs with sufficiently advanced prostheses? It's hard to imagine otherwise.[33]

None of which means that prosthetics will necessarily converge in their appearance on their biological precursors. For purposes of efficiency or economy, aesthetics or personal statement, some prosthetics wearers have begun to favor *non*-natural-looking artificial limbs.[34]

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Flexing motors, not muscles

It's likewise hard to imagine that motorized exoskeletons will benefit only the disabled. The movie *Aliens* (1986) showed us the wearable forklift (also handy for hand-to-hand combat with acid-for-blood extraterrestrials). The movie *Edge of Tomorrow* (2014) showed us strength-and-armament enhancing battle armor. So had, way back in 1959, Robert Heinlein's novel *Starship Troopers* (we will not speak—ever—of the 1997 movie).

Nor will we wait long for such tech. DARPA's "warrior web" project is already working on exoskeletons to assist soldiers.[35]

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An out-of-body experience

As BMIs and robotics improve, the next step—entire prosthetic bodies—becomes imaginable. An ALS patient or a quadriplegic might, by the power of his mind and the availability of a sophisticated, mind-controlled robot, remain at home or hospital *and* be out in the world. Such was the premise of the 2009 movie *Avatar* (in which the teleoperated body mimicked the form of an alien) and John Scalzi's 2014 novel *Lock In*.

Are full-body, BMI-controlled prostheses farfetched? DARPA doesn't believe so.[36]

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Segue

We've covered a lot of ground, from a genre survey of species improvement to eugenics, genetic enhancements, organ replacements, and physical prostheses. Next time, we'll tackle a yet more ambitious topic: changes to the brain and mental prostheses.

Footnotes:

1 *Inquiries into Human Faculty and Its Development,* Francis Galton, 1883.

2 *Science Fact and Fiction: An Encyclopedia* (2006), Brian Stableford, editor, article on Eugenics.

[3] See *http://en.wikipedia.org/wiki/Eugenics#Supporters_and_critics*.

[4] *The Skylark of Space,* E. E. "Doc" Smith and Lee Hawkings Garby, was serialized in *Amazing Stories* in 1928 but not published in book form (with updates) until 1946.

[5] See *http://en.wikipedia.org/wiki/Genetically_modified_food_controversies*.

[6] The technology *is* coming to cut chromosomes and insert genes at precisely targeted locations. CRISPR/Cas, a DNA-editing system adapted from an immune-system mechanism of some bacteria, is in early stages of commercialization.

See "Breakthrough DNA Editor Borne of Bacteria," Carl Zimmer, *Quanta Magazine*, February 6, 2015, *https://www.quantamagazine.org/20150206-crispr-dna-editor-bacteria/#ixzz3cyQlekr5*.

[7] "An integrated encyclopedia of DNA elements in the human genome," The ENCODE Project Consortium, *Nature,* September 6, 2012, *http://www.nature.com/nature/journal/v489/n7414/full/nature11247.html*.

[8] "Efficacy of Gene Therapy for X-Linked Severe Combined Immunodeficiency," Salima Hacein-Bey-Abina et. al., *New England Journal of Medicine,* July 22, 2010, *http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2957288/*.

[9] "Exclusive: First gene therapy drug sets million-euro price record," Ludwig Burger and Ben Hirschler, Reuters, November 26, 2014, *http://news.yahoo.com/exclusive-first-gene-therapy-drug-sets-million-euro-173717146--finance.html*.

[10] "Pfizer bets on gene therapy as technology comes of age," Ben Hirschler, *Reuters,* December 8, 2014, *http://www.reuters.com/article/2014/12/08/us-pfizer-gene-therapy-idUSKBN0JM1MK20141208*.

[11] "Gene Boosts Muscle Strength: Mighty Mice Raise Hopes For A Stronger Life," William J. Cromie, *Harvard University Gazette,* February 11, 1999, *http://news.harvard.edu/gazette/1999/02.11/muscle.html*.

[12] "Low insulin-like growth factor-1 level predicts survival in humans with exceptional longevity," Sofiya Milman et. al., *Aging Cell,* March 12, 2014, *http://onlinelibrary.wiley.com/doi/10.1111/acel.12213/pdf*.

[13] "Obesity gene therapy: Slimming immature rats," R. S. Ahima, *Gene Therapy* (2002) 10, *http://www.nature.com/gt/journal/v10/n3/full/3301920a.html*. Alas, leptin therapy appears to have only limited applicability among humans.

[14] "Hair-Loss Treatment with Hair-Loss Gene Promotes New Hair Growth, Regulates Male-Pattern Baldness and Graying Hair," Columbia Technology Ventures, *http://innovation.columbia.edu/technologies/2419_hair-loss-treatment-with-hair-loss-gene-promotes-new-hair-growth-regulates-male-pattern-baldness-and-graying-hair*.

[15] See *http://bleacherreport.com/articles/1471562-lance-armstrong-confesses-to-peds-what-is-erythropoietin-epo-blood-doping*.

[16] In 2011, Swedish physicians gave a cancer patient a replacement trachea (windpipe). This synthetic organ combined a plastic replica of the trachea with a living cover grown from stem cells taken from the patient's bone marrow. Given the plastic substrate, this implant has elements of both artificial-organ technology and regenerative medicine.

See "Cancer Patient Gets First Totally Artificial Windpipe," Michelle Norris, *Health News from NPR,* July 8, 2011, *http://www.npr.org/templates/transcript/transcript.php?storyId=137701848*.

[17] Biological pacemakers, based upon stem-cell and genetic-engineering technologies, are another possibility. See "Repairing A Broken Heart: Moving Beyond Electronic Pacemakers," Richard B. Robinson, in the November 2011 issue.

[18] "New Wearable Artificial Kidney Improves Mobility," Meg Barbor, *Medscape,* February 9, 2015, *http://www.medscape.com/viewarticle/839462*. (Subscription required.)

[19] "Diabetes Has a New Enemy: Robo-Pancreas," Philip E. Ross, *IEEE Spectrum,* May 27, 2015, *http://spectrum.ieee.org/biomedical/bionics/diabetes-has-a-new-enemy-robopancreas*.

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http://spectrum.ieee.org/automaton/biomedical/bionics/dean-kamen-luke-arm-prosthesis-receives-fda-approval.

[23] "DARPA and OSRF Developing Next-Gen Prosthetic Limbs in Simulation and Reality," Evan Ackerman, *IEEE Spectrum,* 12 Feb 2015, *http://spectrum.ieee.org/automaton/robotics/medical-robots/darpa-and-osrf-developing-nextgen-prosthetic-limbs-in-simulation-and-reality/.*

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[25] In the February 2002 *Analog* issue.

[26] "How to Control a Prosthesis With Your Mind: New brain-machine interfaces that exploit the plasticity of the brain may allow people to control prosthetic devices in a natural way," Jose M. Carmena, *IEEE Spectrum,* February 27, 2012, *http://spectrum.ieee.org/biomedical/bionics/how-to-control-a-prosthesis-with-your-mind* .

[27] "How to Catch Brain Waves in a Net," Nitish V. Thakor, *IEEE Spectrum,* August 21, 2014, *http://spectrum.ieee.org/biomedical/bionics/how-to-catch-brain-waves-in-a-net.*

[28] "Quadriplegic Woman Moves Robot Arm With Her Mind," Charles Q. Choi, *LiveScience,* December 17, 2012, *http://www.livescience.com/25600-quadriplegic-mind-controlled-prosthetic.html.*

[29] "Mind-controlled exoskeleton kicks off World Cup," Stephanie Smith, *CNN,* June 13, 2014, *http://www.cnn.com/2014/06/12/health/exoskeleton-world-cup-kickoff/.*

[30] "Cheap 3D printed robotic arm controlled by the mind," Joel Flynn, *Reuters,* June 1, 2015, *http://news.yahoo.com/cheap-3d-printed-robotic-arm-controlled-mind-150307835.html.*

[31] Wearers of the Flex-Foot Cheetah are sometimes referred to as "blade runners," a comment upon the device's narrow profile and a reference to the superhuman "replicants" in the 1982 SF classic film *Blade Runner* (based on the 1968 Philip K. Dick novel *Do Androids Dream of Electric Sheep?).* More recently, Oscar Pistorius is better known for his culpable-homicide conviction following the shooting death (an accident, he claims) of his girlfriend.

[32] "The End of Disability: Prosthetic and neural interfaces will do away with biology's failings," Eliza Strickland," *IEEE Spectrum,* May 27, 2014, *http://spectrum.ieee.org/biomedical/bionics/we-will-end-disability-by-becoming-cyborgs* .

[33] "No one who works on the biomedical frontier believes that humans will be content with using advanced prosthetics and brain implants only for repair. Once these technologies have been proven safe and reliable for people with disabilities, some people with unimpaired bodies will start clamoring to use them as technological augmentations." Op. cit.

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About the author

A physicist and computer scientist, Edward M. Lerner toiled for thirty years in the vineyards of aerospace and high tech. Then, suitably intoxicated, he began writing science fiction full time. When not prospecting beneath his sofa cushions for small change for his first spaceflight, he writes technothrillers like *Energized* (powersats), the InterstellarNet adventures of First *and* Second Contact, and, with Larry Niven, the Fleet of Worlds series of space operas.

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