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C R I T I C A L **FOCUS**

Brian J. Ford

Cultured Meat: Food for the Future

Journalists say the funniest things. "You were quoted as saying that people could create revolutionary food for the future out of living cells," said one recently. "Is it feasible?" Of course it is. What did he think he'd eaten for breakfast? It is curious how easily we overlook the fact that our food is largely composed of cells, either living or dead. Yet, this simple proposition helps make sense of our diet, assists us when we work on how to handle food safely—and offers radical new ideas on how we could mass-produce food for the mushrooming human populations of the near future.

From living animal cells we can mass-produce food for an expanding population that is facing global shortages.

As a student, I was dissatisfied with the way that food, safety, microbiology and hygiene seemed to be confused in the minds of the teachers. That was why I wrote the textbook *Microbiology and Food* when I was still in my twenties, and it became widely consulted. Recently, I was accosted after giving a lecture by a New Zealand professor who said he still used the book regularly to illustrate his lectures. Although I was glad to hear that, the book is woefully out of date, and I hope his students are aware of that. *Microbiology and Food* looked at these interrelated subjects from the single viewpoint of the living cell: the cell as feeder, cells as food, as the maker of food and as the agent of spoliation. The book did provide a pleasingly coherent basis from which to discuss these subjects. Lurking behind the thesis was the idea that food can usefully be considered from the standpoint of the living cell, and that remains a crucial concept.

I returned to the topic in *Microbe Power, Tomorrow's Revolution*. In this book, I looked at the production of cell cultures on a large scale as food for a hungry world. At the time, *Fusarium venenatum,* a fungus found in a wheat field, was showing promise as a candidate for the mass production of proteinaceous foodstuffs, and I envisaged factories in the Arctic producing these novel foods on an unprecedented scale. My proposal to construct these factories in the icy wastes of the far north took into account the fermentation process that would generate large amounts of heat. Rather than harness this energy (which would be the modern answer), I proposed that the low Arctic temperatures would offer the perfect heat sink for the process. At the time, the resultant warming seemed inconceivably small. In an era when explorers find their way to the North Pole blocked by deep lakes of liquid water, when the Northwest Passage is being opened for traffic, and when submarines can surface at the melted pole for a game of football on the surrounding ice, the idea of Arctic warming does not seem so inconsequential. Thank heavens nobody took up my proposal and developed it in practice.

The subject is current again because of pressures on our food supply. Humans can no longer afford to eat meat in the future as we have done in the past. Livestock production imposes a vast burden on global resources—a burden that the expanding world popu-

In 1930, Frederick Edwin Smith (left), an eminent British writer and politician, predicted the era of cultured meat, saying it would be possible in a culture "to grow a large and . . . juicy steak" instead of slaughtering a steer. Winston Churchill (right), who was a close friend of Smith's, appropriated his ideas in 1932 by writing about how one could grow chicken breasts instead of farming chickens. Churchill's words are widely quoted, whereas Smith's have been largely forgotten.

lation can no longer sustain. A 1981 article in *Newsweek,* "The Browning of America," pithily said, "the water that goes into a 1,000 pound steer would float a destroyer." Estimates now suggest that it takes about 2,500 gallons of water to make a pound of beef, though it depends on whom you ask for the estimate. The American meat industry puts the demands far lower, at less than 450 gallons, but even that is an unsustainable amount of water.

Imagine if we were able to culture such food in factories. We might be able to manufacture virtually limitless supplies at a greatly reduced cost and a smaller environmental impact. There is an upsurge of interest in the possibilities of meat produced from cultured cells *in vitro*. America has shown little interest, but there is active research elsewhere, particularly in the Netherlands. But can we change attitudes so that scientists start to see food from the viewpoint of the living cell? When a successful product emerges, what should we call it? How does it fit into a broad social context? Can it work? Does it matter? Will it solve our current demand for food? What will be the environmental consequences? Would people accept it, and how diverse are public attitudes toward the consumption of meat?

Culturing meat is certainly becoming fashionable, but it is not a new concept. In 1932, Winston Churchill wrote: "Fifty years hence we shall escape the absurdity of growing a whole chicken in order to eat the breast or wing by growing these parts separately under a suitable medium." This idea seems very farsighted, and it has often been quoted. There are more than 3,500 websites that cite Churchill's words. Yet the idea was not his own. Two years earlier, the writer and conservative politician Frederick Edwin Smith, First Earl of Birkenhead, and a friend of Churchill's, had written: "It will no longer be necessary to go to the extravagant length of rearing a bullock in order to eat its steak. From one 'parent' steak of choice tenderness it will be possible to grow as large and as juicy a steak as can be desired." Very few websites include his ideas; about 20 sites quote the second sentence and only four currently publish the whole quote. Yet this was an important breakthrough in thought, and it dates back more than 80 years. Since then, little has happened.

DEPLETING RESOURCES

Although we are being urged to cut down on burning fuels for transportation, it is important to realize that rearing livestock for meat production pumps more greenhouse gases into the atmosphere than the entire transportation network of the world. The production of meat consumes 8% of all freshwater and involves 30% of the ice-free land surface of the earth. This is the same as the amount of land surface unsuitable for grazing or cultivation, and much the same as the area covered by forests.

The West is greedy. American figures show that the amount of food and grains that supply the average world inhabitant is 1,353 pounds *per capita* annually. It is far less in China, 1,028 pounds, but in the United States the amount of grain used to raise beef raises the personal annual consumption to 3,265 pounds, nearly three times as much as the average across the world. More species of wildlife have been driven to extinction by raising livestock than through any other cause. In Central America, more than a quarter of all the rain forests have been converted to cattle rearing since 1960. In Panama and Costa Rica, 70% of the native tropical rain forest has been burned and converted for rearing cattle. Roughly 40% of the land area of Brazil has been cleared for raising beef.

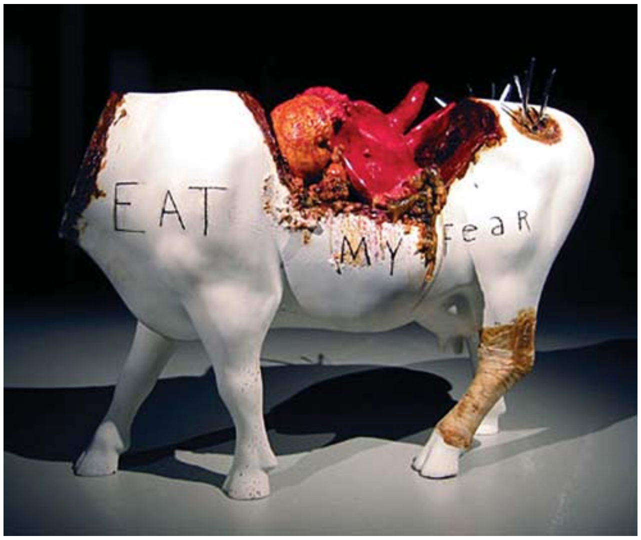
Pressures on resources have led to a sudden increase in the productivity of animal farming. For all their reputation in the Western world as "animal lovers," the British still produce eggs in battery farms where several hens can be confined in a cage measuring no more than 18 x 20 inches (approximately the same size as a microwave oven). With a wingspan of only 30 inches, we can see that severe constraints are put upon these birds. A hen in its wild state lays about 20 eggs each year, but selective breeding has given us breeds that lay 300 each year, approaching one every day.

In the U.S., chemical growth promoters are widely used to boost the amount of meat obtained from each animal. Less than a decade ago, a range of antibiotics was routinely fed to European farm animals to increase the amount of meat they produced. Questions have arisen over the long-term effects on human health, and many countries around the world simply ignore new regulations designed to protect the consumer. Meat farming is globally important, and we need to face the realities as we lurch unsteadily into the future. Beefsteak has long been popular in the U.S., more so than in almost any other country (except Argentina). In America, cattle are iconic, virtually a symbol of good eating and a hallmark of virility. In 1999, cattle became a major art form when Chicago held the inaugural "CowParade" street exhibit in which life-size fiberglass bovines were decorated by noted artists. Some were emblazoned with pastoral scenes and abstract designs, while others were adorned with bizarre clothing, flowers and flags. At the exhibit's staging in New York City the following year, a sculpture by filmmaker David Lynch portrayed a cow in the process of being rendered for human food. Its head was missing, and a large bloody gash had opened the animal from the backbone to show the viscera. This sculpture was entitled "Eat My Fear." Some spectators were so upset at the image of a cow being butchered for food that Lynch's sculpture was removed from the exhibit. The practical realities of beef production are something people tend to find unacceptable, even in America. The bloody nature of the butchering process is something we choose to ignore, even though that scrumptious steak on your plate has come directly from the slaughterhouse.

IMMINENT FAMINE?

Alternatives to meat avoid any unsavory killing, of course, so what about producing cultures of cells as food? In London in the 1820s, Thomas Malthus had predicted that agriculture could not keep pace with population growth, and the view had remained current. By the 1950s, it was widely believed that the world was shortly heading for a massive famine, and enterprising food companies began to look at novel proteins and investigated cell cultures as a possible answer to a global food shortage. Fungus colonies were known to be potentially nutritious, and cultures of possible fungal products were soon under way. In 1967, scientists at the British food manufacturer Rank Hovis McDougall (RHM) isolated an ascomycete mold, named *Fusarium venenatum,* from soil in a wheat field, which proved to be easy to culture in bulk. In 1980, RHM were authorized to produce foods made from *Fusarium* for public consumption. The product is marketed under the name of Quorn, and it is now invading the American market.

In the event, the predicted global food shortage didn't happen at the time. For decades, right up to the new millennium, scientific agriculture continued to keep pace with demand. When there have been tragic episodes of mass starvation, they were not due to a shortage of food—only to a shortage of political will-



"Eat My Fear," a sculpture by David Lynch, was removed from New York's "CowParade" in 2000 after spectators became upset at the portrayal of a cow butchered for food. The practical realities of beef production are something people tend to find unacceptable.

ingness to distribute it. The well-known famine of Ethiopia in 1984 was caused by political intransigence. The Ethiopian government was exporting grain and devoting almost half of the gross national product to military expenditure at the time, because they were fighting a breakaway movement in Eritrea. Trucks bearing food aid were not permitted to enter the rebellious territories where the population was starving. The 2011 famine in Somalia was similarly exacerbated by extremists who refused to allow relief trucks to enter the territories they controlled.

There has been enough food for everyone for decades. In Europe, we even saw "wine lakes" and "butter mountains" as surplus production was stockpiled. For a television program, I waded through a huge warehouse containing thousands of tons of surplus grain. Huge amounts of food were being destroyed. The demand for a substitute food like Quorn had been overtaken by events, and the business model became obsolete. Instead, the makers decided to market it as a health food. There are plenty of precedents. *Tempeh* is a traditional meat substitute produced in a time-honored fashion in Indonesia by fermenting cooked soybeans with the common pin-mold *Rhizopus*. The fungal threads bind the bean protein together into a tasty mass that contains all the essential amino acids, which makes it an excellent vegan food. A similar traditional food is the bean curd *tofu*, which looks like a soft cheese. It originated in China as *doufo* and is made in Japan by coagulating curds of protein from soy milk. Tofu is increasingly popular in the West, because it is rich in nutrients and can lower blood levels of low-density lipids—popularly known as "bad cholesterol"—by 30%.

People like fungus proteins. In a newspaper interview that was widely published around the world in 2005, I argued: "The widespread acceptance of meat substitutes such as Quorn, a cultured fungus, shows that the time for cultured tissue is near." If this could be achieved, we would be able to mass produce beefsteak without slaughtering another living creature. The objection is sometimes termed the "yuck" factor. The term was put to me by a young journalist from the science magazine *Focus*, who recently interviewed me on the topic. I don't think it matters. Quorn is based on highly refined technology and offers the consumer a food that nobody can obtain in the natural course of events. It is entirely unnatural, and high in potential yuck factor, yet people are buying it in increasingly large amounts.

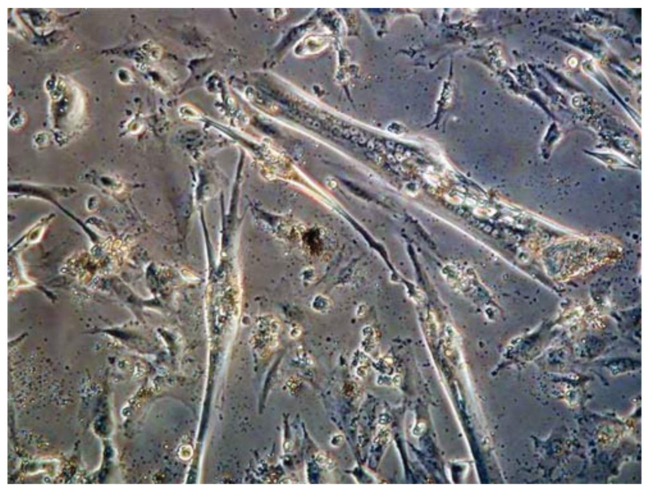
BACTERIA ARE BASIC

So, could it be done? The first requirement is a food source for the growing meat cells, and cyanobacteria are a clear candidate. Cyanobacteria are fast-growing simple photosynthetic bacteria with a dry weight protein content of up to 70%, and they can easily be grown in mass culture. So here we have a basic feedstock that could be used to make a growth medium. We can culture animal cells and have been able to do so for a century. In 1885, the pioneering Germany embryologist Wilhelm Roux maintained living tissues from the medullary plate of an embryonic chick in saline solution for several days. Ross Granville Harrison was an anatomist at Yale University who immersed himself in *in vitro* research as a way to escape lecturing (which he abhorred), and a century ago he launched the new science of tissue culture. He produced a torrent of papers—up to six in one year—on transplanting limbs in embryos, and in 1912, published "The Cultivation of Tissues in Extraneous Media" in *Anatomical Record*. This is interesting in itself—the practice of tissue culture predates Smith's prediction by 18 years.

I was first involved with the subject in 1960, when I worked on tissue culture in my year with the Medical Research Council in the UK before going to university. I had speculated on the mass production of cultured cells as human food in my book *Microbe Power,* published in 1976. In 2000, my book *The Future of Food* was published. Although cultured meat was not a topic I addressed in that book, I was asked to discuss cultured meat in several programs until 2007, when I was invited to join New Harvest, a nonprofit organization, to promote advances in meat substitutes, including cultured meat. Two years later, I was invited to contribute a chapter for a book in a series entitled *Death and Anti-Death*. The request came from Dr. Charles Tandy of Ria University Press in Palo Alto, Calif., who formally invited me to contribute a chapter on cultured meat. It appeared in December 2009, and was the first-ever chapter to be published on the subject. Many of the ideas in this column were first published in that book.

Research had been interminably slow to start until NASA awarded a grant in 1999 to biologists Morris Benjaminson and Jim Gilchriest at Touro College in New York. At around the same time, a pioneering patent was published in the Netherlands, which described the production of cultured muscle cells in a three-dimensional structure, "free of fat, tendon, bone and gristle." Healthy as this may seem (nobody wishes to find unexpected fragments of bone in a succulent cut of steak), it is an important fact that it is primarily the fat and connective tissue that give striated muscle its meaty texture and appetizing taste. Many of the recent converts to healthy eating will already have experienced something similar. Rather than purchasing ready-made hamburgers, it has become popular to buy lean, red meat and make the burgers at home. Lean meat makes a dry and hard burger, but for best results the meat needs to be laced with fat—or "well marbled" as the *cognoscenti* like to say. Without the fat, the homemade hamburgers are not as appetizing. The promised fat-free culture of muscle fibers will not give us beefsteak.

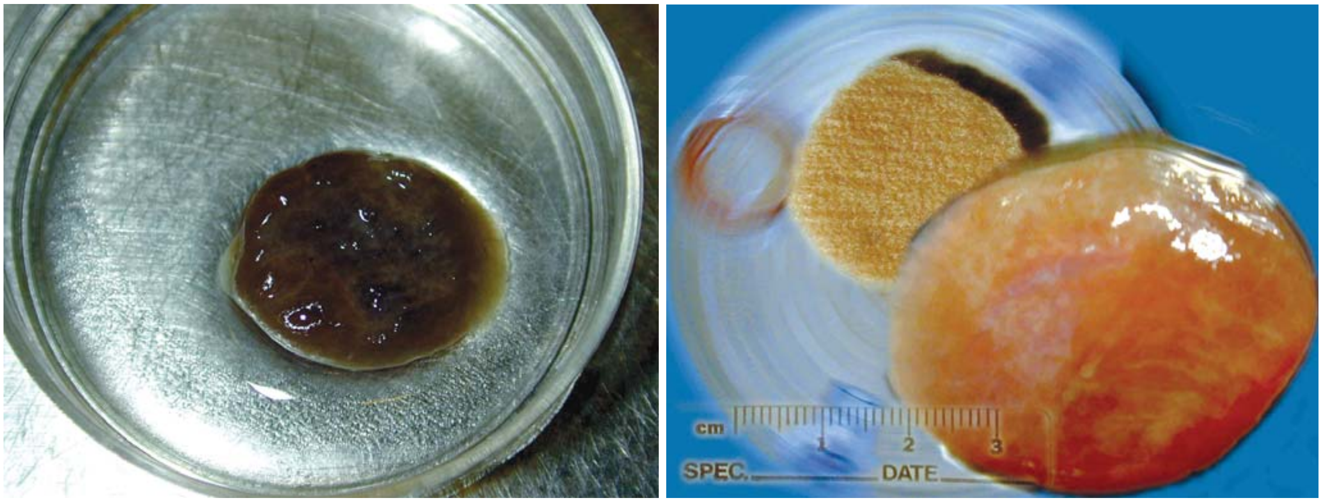
Prof. Bernard Roelen of Utrecht University in the Netherlands has cultured stem cells from porcine voluntary muscle. Some differentiation can be seen in this low-power view under phase contrast microscopy. (Micrograph color has been optimized by the author.)



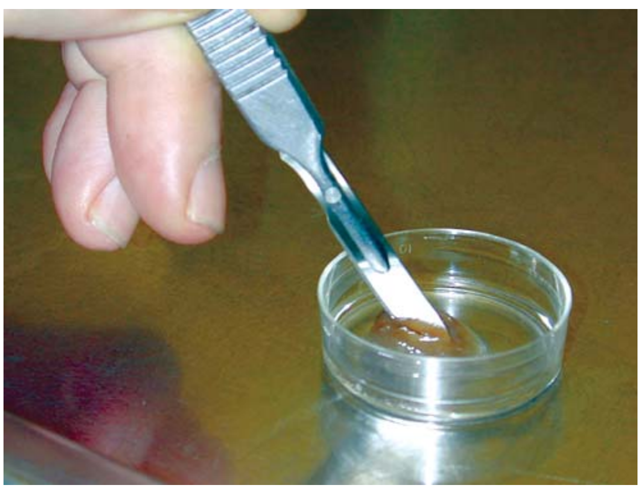
Under a high-powered phase contrast microscope, the elongated precursor cells are conspicuous. However, because these are in early development, no striations are visible, which would be a feature of mature muscle cells. Striations have been seen only with immunostaining, so these represent the early stages of research.

LET'S GET CULTURED

The culture of muscle fibers introduces a new paradox. Striated muscle is formed when maturing precursor cells fuse and lose their identity, therefore each fiber is multinucleate and cannot itself proliferate. New muscle tissue arises only from the fusion of the precursor cells. The original Dutch process envisages the production of a collagen matrix (the basis of connective tissue) with muscle cells that are artificially induced to divide. In 2001, John F. Vein took out U.S. Patent No. 6835390 for "A non-human tissue engineered meat product and a method for producing such meat product." Vein proposed to produce cultured meat by growing colonies of muscle and adipose cells in an integrated manner that could imitate beef, chicken and fish products. That might yet prove to be an answer. In the following year, a paper for *Tissue Engineering* by Jason Matheny (who went on to found New Harvest) and colleagues launched a discussion of the feasibility of laboratory-grown meat. And in 2008, the board of People for the Ethical Treatment of Animals (PETA) announced a $1 million prize for the first company to release a food product that successfully brings cultured chicken meat to consumers in at least six U.S. states by 2016. Governments are starting to become interested. In 2007, the Dutch government invested 2



Australian artists Oron Catts and Ionat Zurr maintained cultures of "prenatal sheep skeletal muscle and degradable PGA polymer scaffold" (left) for four months as part of the "Tissue Culture and Art Project" at the University of Western Australia. Catts, Zurr and Guy Ben Ary also presented an example of cultured muscle called "Study for Disembodied Cuisine" (right). Separately, James King, an American designer, is now making "cultured meat" creations of his own. Scientists find it curious how much attention the subject is attracting in the art world.



Catts and Zurr produced tissue cultures during a research fellowship in the Tissue Engineering and Organ Fabrication Laboratory at Harvard Medical School.

million euros in cultured meat research at the universities of Utrecht, Eindhoven and Amsterdam. Then, in April 2008, the Food Research Institute of Norway held a pioneering conference on cultured meat, and matters began to gain momentum at last.

In the U.S., there has been less interest. The National New Biology Initiative, announced by the National Academies in September 2009, promised much in fields such as genomics and applied genetically modified technology by bringing together physicists and engineers, computer scientists and chemists with the bioscience community. Systems biology lay behind this. The problem here is that these are familiar and fashionable sciences, not new and exciting ones. My personal belief is that we need a greater emphasis on whole cell biology, rather than more reductionism, and those American authorities did not propose to fund work on cultured meat. Their initiative sought to raise the international profile of American science, but it does so by looking backwards (or sideways at best). It is to the far future that we need to gaze, and the production of cultured meat is a clear candidate for high priority support. One of the few research scientists working in this field in the U.S. is Dr. Vladimir Mironov at the Medical University of Charleston, S.C. The research team has already identified the myoblasts from edible animals that they can clone, and they have developed a method of biofabrication of spheroids of cultured muscle cells. Their techniques could be scaled up.

When there is a product, what should we call it? The generally accepted term is *in vitro* meat, though *ex vivo* has attracted some currency, and my personal preference of "cultured meat" is useful in that it is a term that is meaningful to a wider public. All new scientific procedures need abbreviations, of course. Already we have "single cell protein" (SCP) and "meat protein production system" (MPPS). Now the first acronym, "*in vitro* meat production system" (IMPS)—imps?—sounds like gremlins at work. There must be better alternative acronyms. One could call the emerging discipline "biologically extraneous edible food from science-based technological extruded alternative cell kinetics," but this gives us an acronym that is already in use. There is a serious need to find a convenient term for this novel concept. I find "cultured meat" to be a perfectly satisfactory term, but a marketing executive might well propose something better than that. A generally accepted term is a prerequisite for widespread discussion on the focus for new research.

There are potential health benefits of cultured meat. Domesticated farm animals deliver levels of saturated fats that are considered unhealthy. With cultured meat, we could arrange for optimum levels of omega-3 and omega-6 oils in the products, for instance, and regulate their ratios. That's the good news, but there are practical problems to face. Culture would need to be sterile and meticulously monitored. Excretory byproducts are generated by animal cells in culture, just as they are in those growing in the living animal, and they require high throughputs of oxygen and waste gases. They also generate heat energy, which could be a useful byproduct. These are major issues that need sensible management policies, and in my view, we now have an increasing need for the new technology of cultured meat. It could produce a potentially healthier product and at a lower financial and environmental cost.

RECIPE FOR TASTIER MEAT

The need to reconcile the product with the sheer complexity of muscle as found in the animal is a problem we can tackle in several different ways. The emergent discipline of biofabrication allows us to assemble cells into an appetizing and nutritious product. This is a fast developing technology, and it even has a dedicated new journal, *Biofabrication*. If we can perfect this technology, then genetically modified gene-splicing could permit us to produce cultured forms of meat with the very best lipid spectrum, which can appeal to consumers of the future. One line that I would advocate centers on stimulating stem cells to grow in actively differentiating communities, which lead to the development of fully formed and diverse tissues that, in a cohort, produce a naturally differentiated tissue. Because the mammalian embryo manufactures a fully formed limb from stem cells, we could ultimately do the same in the laboratory. The fact that some adult salamanders (but not all) can already do this shows that this is a practical problem we can solve.

Pioneering progress has already been made by the Touro College team with tissue culture of muscle from *Carassius auratus*, which has scored well with a panel. They only smelled it, mind you, because there was not enough to taste. The name may not be familiar, because *C. auratus* is a version of the Prussian carp, known to us as the common goldfish. No, it's not going to feed the world, but this is a tissue source that can be raised without incubators, and it offers proof of concept. Cell lines, like the creatures from which they originated, are mortal and will normally die out after a predetermined number of mitotic divisions. This is known as the Hayflick Limit and is related to the telomeres, situated at the ends of the chromosomes, which become shorter with each mitosis and are correlated with the senescence of the cell. As the telomeres shorten, so does the life of the cell line.

This is all understood, but less well known is that some cells break the rule. Occasional cell lines are known to be immortal. The familiar house plant *Tradescantia zebrina* is reproduced vegetatively and does not exhibit senescence, even though there must be millions of tons of essentially the same plant around the world, all of them many decades old. Some animal cell lines have also acquired immortality. Cultures of transformed HeLa cells are used in laboratories around the world. These were originally obtained from an American hospital patient named Henrietta Lacks who was suffering from cervical cancer. Mrs. Lacks died on October 4, 1951, yet her cells exist in laboratories around the world, and there must be hundreds of tons of her tissues still living. They have taken so well to culture that they are a frequent contaminant of other cell lines, and they now have the longevity and virulence of a culture of microbes.

In the Netherlands, there has already been interpersonal controversy triggered by the research. One senior scientist, Prof. Willem van Eelen, was quoted in *Scientific American* in June 2011, as saying that he didn't know what useful work the government funds were supporting. "The researchers are talking, talking, talking—every year taking more money," he was reported as saying. In Utrecht, a cell biologist who had worked on cultured meat was quick to respond: van Eelen was being naive. "He had the idea that you could put muscle cells in a petri dish and they would just grow, and if you put money into a project, you'd have meat in a couple of years," retorted Dr. Bernard Roelen.

Curiously, one of the most far-reaching research programs came, not from scientists, but from Australian artists. At the University of Western Australia's Centre of Excellence in Biological Arts at the School of Anatomy and Human Biology, there is a group working on a "Tissue Culture and Art Project." Two artists, Oron Catts and Ionat Zurr, have been working with cultured cells. Catts has taken it all seriously. He has

One of the few American scientists involved in cultured meat is Dr. Vladimir Mironov (left) of the Medical School of South Carolina at Charleston (pictured with Dr. Nick Genovese). Mironov is looking to develop an *in vitro* production model for cultured meat that can be scaled up if it could be made commercially viable.

been research fellow at the Tissue Engineering and Organ Fabrication Laboratory at the Harvard Medical School, Massachusetts General Hospital in Boston and visiting scholar at the Dept. of Art and Art History at Stanford University. He is currently Visiting Professor of Design Interaction at the Royal College of Art in London. He and Zurr have speculated on the "semi-living steak" and "victimless leather." I would like to tell them that there's nothing "semi" about the living steak, and victimless leather may be a misnomer. Leather is a byproduct, after all, and not the reason cattle, sheep and pigs are slaughtered—but that's equivocation. These two artists have done more to advance thinking in this field than many of the professional scientists.

SUCCESSFUL APPROACHES

We can now see that there will be three approaches to growing animal tissues in bulk in our quest for new foodstuffs. A successful product can be reliably produced by 1) regularly replenishing the culture with fresh cells, 2) using an immortal cell line, or 3) immortalizing an existing cell line. Cells derived from an animal malignancy—like HeLa cells—are amenable to culture. They would provide a good starting-point, however the "yuck" factor would deter one from investigating the possibilities of using a cell line of transformed malignant cells to produce food.

Embryonic animal stem cells seem to me to be another candidate, and progress has been made by culturing myoblasts on a scaffold of collagen. There have been experiments with adipose tissue-derived adult stem cells (ADSC), which are isolated from subcutaneous fat and can differentiate into cells including myoblasts, chondrocytes, adipocytes and even osteocytes. When you culture cells from the intima of blood vessels, they show signs of organizing themselves into tubular structures, so we can see that my aim—growing structurally organized complex tissues with their own network of blood vessels—is not so impracticable.

Beneath it all lies the way in which the single cells behave, and little has ever been discovered about the formation of new muscle tissue. One focus of interest is the repair of damaged muscles, and the nature of the key cell types involved is being revealed by Dr. Amy Wagers and her colleagues at Stanford University School of Medicine. They have located myogenic satellite cells from which new muscular tissue will derive. These cells live underneath the basal lamina of mature muscle fibers. They are not the only cell types to be involved. As you might expect—in such a complex structure as muscle—stem cells from other sources may be involved in the production of blood vessels, nerves and connective tissue. The satellite cells are not just of one type, either. They seem to be a mixed community covering many different phenotypes, each of which may have its own role to play. It may be that the study of human muscle regeneration will help to inform us on the most propitious approaches to use in culturing meat.

An intermediate stage in our progress towards industrialized meat production may be the growth of animal cells (much as fungus hyphae are cultured) and texturizing them to acquire a meat-like texture. The development of the existing meat substitutes has given us a good grounding in techniques that allow us at will to alter the "mouth feel," as food technologists call it. The mass-production of cultured animal cells would allow the manufacturer to incorporate fibrous collagen, admixtures of striated muscle tissue and adipocytes (or fatty components derived from them) so that the meat product is made in the production plant through bio-assembly, rather than growing it like an explant. In this way, we could maintain full control over taste, texture, consistency and the nutritive value of the product could be assured. Even if we cannot culture anatomically complex tissues, this bioassembly technology will allow us to produce meat substitutes from cultured components. This has been the approach used by Henk Haagsman and his team at Utrecht, whose research funding was recently renewed by the European Union, as well as

Mironov's team in the U.S. The Americans are currently exploring methods of preventing their tissue spheroids from fusing together as they develop. They are also developing an edible polymer on which cell communities could be assembled. Mironov is currently working on the design of a continuous-flow culture plant that could show the way to produce such cultured meat on an industrial scale, though this research has yet to be published.

ENVIRONMENTAL BENEFITS

This is all happening at exactly the right time. Cultured meat would address so many issues. Because it would be sterile, there would be an end to the outbreaks of the emergent diseases transmitted by manual contact (*E. coli* O157:H7 and *Listeria*, for example). Because the meat would be locally produced, it would reduce the amount of transportation required to deliver the product to the consumer, with a consequent reduction in carbon dioxide emissions. The reduction in cattle-rearing would cut the volume of methane released into the atmosphere from the rumen of cows. (Methane is more than 20 times more efficient than carbon dioxide as a greenhouse gas, even though it is far less abundant in the atmosphere.) And the unsustainable levels of waste nitrate that are released by cattle farms would also be reduced.

We would not be faced, as once I imagined, with an industrial complex in the Arctic producing superabundant food for all. But, just as the world's population reaches unmanageable limits, it could offer a way of providing highly nutritious, safe and affordable meat products for the communities of the future. It could alleviate shortages, reduce pollution, cut human disease and offer a way to increase food production as we seek to ease the pressures on the world's dwindling resources. Cultured meat offers us so much. Once science starts to see our food as a community of cells, and not just as a hunk of protein on a plate, the rate of progress can only increase.

When a future generation looks at how the race was won, they will be surprised at the time it took science to wake up to the realities. Cultured meat will prove to be as important in the future as bread, cheese and beer have been in the past. They too were all made by harnessing the power of the living cell. Above all, it is the cell that matters.

And if it is the cell that matters in creating our food, can it be any cell at all? The range is wider than you might think. It could even include *E. coli*, which is abundant in sewage. In Japan, the Tokyo Sewage Company was aware of the vast volume of *E. coli* cells that comprise one third of the huge mounds of sewage sludge they handle each day. Could this not be a valuable food resource? They reportedly commissioned Prof. Mitsuyuki Ikeda of the Okayama Laboratory in Tokyo to develop an artificial steak from *E. coli* cells.

Japanese scientist Mitsuyuki Ikeda holds the artifical steak he developed from *E. coli* cells found abundantly in Tokyo sewage. Could this be a revolutionary solution to future food shortages?

The experiments worked. The cells were separated, cultured, textured and cooked, and taste panels thoroughly approve of the result. These synthetic steaks are 63% protein, 25% carbohydrate, 9% minerals and 3% lipids. It is an ideal analysis. But is the public going to start buying this revolutionary new product? Currently, it's pretty doubtful, but in the future, when food is scarce, attitudes may have to change.

A sign on the refrigerator in the Okayama Laboratory reminds people of the project for which it is intended: "shit burger," it says. I've encountered a good number of those in the past, but this is the first time anybody has openly admitted the fact.

Correction

The Critical Focus article, "The Leeuwenhoek Specimens," Vol. 59, No. 1, pp 11-19, misstated that the author was the first person to use Leeuwenhoek's original microscope since Leeuwenhoek himself three centuries earlier (page 17, column 1). As the author said, he was the first person to view Leeuwenhoek's specimens through his microscope since Leeuwenhoek three centuries earlier. *The Microscope* regrets the editing error.