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CRITICAL FOCUS

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There Is Always Life After Death

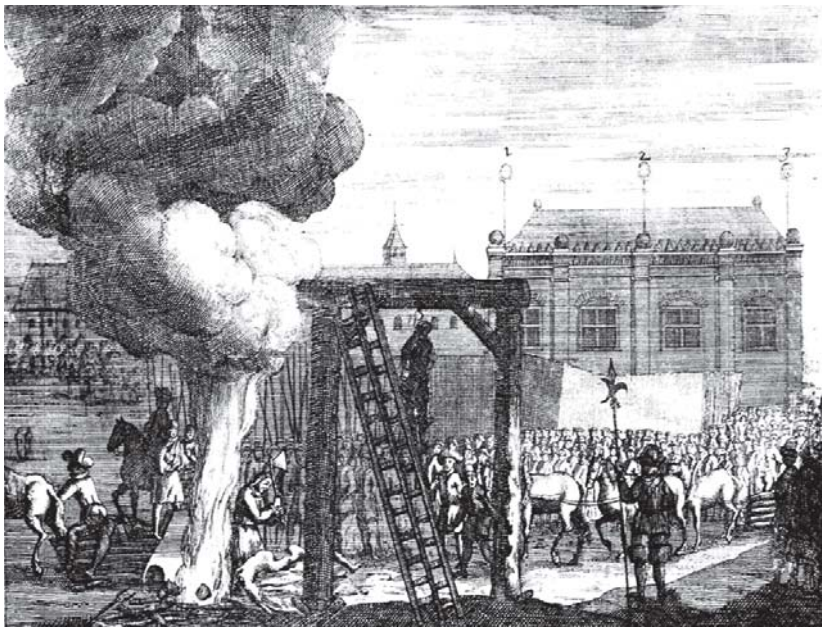
Death may appear as an instantaneous ending, but looking into the microscope reveals that life often persists long after we think people have died.

Birds sang and the sun had just risen when, at 5:30 a.m. on a bright spring morning, with a sudden swish and a thud the silver bright blade of the guillotine slid down its wooden runners and severed the victim's head with a crunch of bone. The ghastly head spurted blood and bounced into the basket. Its eyes were closed. Then the attending physician called the victim's name. The man's eyes opened; their gaze focused on the doctor. The dead man was not lifeless, for he was staring straight back.

It was in June 28, 1905, when Dr. Jacques Beaurieux attended the execution of that condemned man in Paris. The prisoner was Henri Languille, and Dr. Beaurieux watched as the head crunched into the basket and then wrote this gruesome account:

> Here, then, is what I was able to note immediately after the decapitation: the eyelids and lips of the guillotined man worked in irregularly rhythmic contractions for about five or six seconds. This phenomenon has been remarked by all those finding themselves in the same conditions as myself for observing what happens after the severing of the neck. I waited for several seconds. The spasmodic movements ceased … then I called in a strong, sharp voice: "Languille!" and I saw the eyelids slowly lift up, without any spasmodic contractions — I insist advisedly on this peculiarity — but with an even movement, quite distinct and normal, such as happens in everyday life, with people awakened or torn from their thoughts.
>
> Next Languille's eyes very definitely fixed themselves on mine and the pupils focused themselves. I was not, then, dealing with the sort of vague dull look without any expression, that can be observed any day in dying people to whom one speaks: I was dealing with undeniably living eyes which were looking at me. After several seconds, the eyelids closed again … It was at that point that I called out again and, once more, without any spasm, slowly, the eyelids lifted and undeniably living eyes fixed themselves on mine with perhaps even more penetration than the first time. Then there was a further closing of the eyelids, but now less complete. I attempted the effect of a third call; there was no further movement — and the eyes took on the glazed look which they have in the dead.

The prisoner had been decapitated, but was still living after execution. The cells of his body had not died. Henri Languille was alive after his death. And so are we all.



Left: Warwick Castle in England, exhibits this death mask of Oliver Cromwell, who overthrew King Charles I and became the leader of the short-lived British Commonwealth republic in 1649. Cromwell died of natural causes in 1658, but after the monarchy was restored in 1660, it was resolved to exhume the body. Right: It is unusual for people to be executed after they died, but in 1661 Cromwell's body was taken from Westminster Abbey for execution. The body was hanged all day and then beheaded. The head was impaled on a pike until it fell down in 1685 and was finally buried at Cambridge in 1960.

Curiously, the guillotine was not a French invention. The oldest decapitation machine on record is the Halifax Gibbet of Yorkshire, England, which was a 15-foot tall device. The first written record of its use dates from 1280, though local legend claimed it had been introduced in 1066. The Halifax Gibbet was last used to execute a criminal on April 30, 1650, though there are records of a similar execution machine in Nuremberg, Germany, in the 16th century and another in Milan, Italy, in 1702.The guillotine appeared in France in 1792 on the recommendation of Dr. Joseph-Ignace Guillotin who saw it as a quick and painless way of death. Nicholas-Jacques Pelletier, a convicted highwayman, was the first person to be executed April 25, 1792. Since that time, observers have often written of severed heads that grimaced after they fell, and in one case a severed head is supposed to have bitten the ear of the one lying next to it in the basket.

The startling truth is that a decapitated person is not dead. Consider: An immeasurably thin blade moves at incalculably high speed and slices invisibly through your neck as you are clamped bolt upright in a chair. Of course it doesn't kill you. Within your body, nothing has changed. Well, high aortic pressure might dislodge the head like a beach-ball spinning on a jet of water, so we'd best imagine that you were wearing a heavy hat to keep the head in place. The blade, of almost infinite thinness, has severed the head from your body but nothing has killed you. Your cells are as alive now as they were a minute ago. Just make sure that nobody slaps you on the back by way of congratulation.

[As this article was about to go to press, this point was discussed with Professor Michael Langford over dinner at Cambridge University. He smiled and said: "This concept exists in a traditional anecdote that has long circulated in China. A Samurai took offense at a peasant and lunged at him with his scimitar. The man smiled and said: "Ah, you missed me." Smiling, the Samurai replied: "Wait until you bow your head."]

Although decapitation seems to spell instantaneous death, those who observed guillotined victims knew that decapitation did not mean an instant demise. In the laboratory we have recorded examples of creatures surviving without a head. As we shall see, there have even been experiments where a head was able to live without its body.

The reason we imagine that decapitation means instant death is because humans are regarded as a kit of parts that nature has assembled into a unified form:

arms, legs and a head; a heart and liver; a set of genitals and an umbilicus. Working all my adult life with living cells has given me a radically different insight. You may know that I visualize humans, not as clusters of organs, but as communities of cooperative living cells. We are fruiting bodies, toadstools with attitude. I see us as choreographed communities of largely autonomous microscopical entities that have evolved together for the common good. There is not just one "you" — there are 50 trillion. You're not a person so much as a colony. Endless ramifications stem from this revealing view of human nature, and none is more profound than how I view of the end of life.

THE CELLULAR VIEW

Picture the scene. Grandfather lies in his posh bed, surrounded by mournful relatives. He has lain there for a week. There has been little change. Then, with a sudden tension, he gasps. For a moment it looks as if he's trying tremulously to rise from the pillow — but it is just a last, agonizing moment as, with a final fluttering breath, he sinks back and exhales softly for the last time. His nearest and dearest take turns to lay their cheeks on his, whispering soft words of farewell. Tears glisten in the shards of light from the patterned lampshade as a life, well lived, has ended. "Time of death? Ten-thirty."

But he is not gone. The dead man was listening all the while.

Now picture the scene microscopically, from the viewpoint of the cells. As blood circulation diminished — the result of lying on a mattress for a week — the cell populations in the bloodstream had been changing. There were fewer red blood cells; a lowered demand for oxygen from the lack of mobility resulted in a reduced requirement for functioning erythrocytes, and they were being replaced slower than they were being removed. The smaller blood platelets were starting to show signs of stickiness, and threads of fibrin were precipitating in the plasma, wafting through the major blood vessels like gossamer silk and slowly dissolving as the enzyme fibrinolysin was released to maintain the balance.

At the juncture of the coronary artery that had, for a lifetime, led a supply of freshly oxygenated blood to the heart's left ventricle, lay a fatty plaque that had slowly grown over the years. Yellow, like the beef fat grandfather so enjoyed eating, this alien body had been progressively enveloped by healing leukocytes and they had done all they could to militate against its effects. With considerable ingenuity, the cells had formed a fibrous anchor that served to lock the lesion in place, but they could do little about its tendency to acquire fresh deposits of fat. This hydrophobic hump became a focus for the minute lipid specks that wafted along in the plasma. From being a flat creamy patch in the middle years, it was now a rough lump projecting from the artery wall. This spelled trouble, threatening the supply of blood to the heart.

The local cell population had also done their best to adapt. Smooth muscle bands had contrived to leave the vessel as open as they could. Blood vessels upstream of the plaque had sorted out among themselves how to expand so that blood could be distributed more efficiently into the muscle bands. Blood pressure had been raised, to help increase the flow through the stricture, though the physicians kept insisting that it was reduced through medication. Through the choreographed interaction of the cells, and the doctors' intervention, the fatty plaque had been kept firmly in its place. But today, that was about to change.

As a pack of platelets cruised past the fatty growth, their trailing fibrinous tails caught on the plaque and stuck like glue. Passing erythrocytes, not so much biconcave wheels but flat bags of liquid gel that could distort like half-set jelly, ran along these threads and held fast to them like balloons on strings. These penderocytes exist to stop blood flow ("Critical Focus: The Curious Paradox of Blood," *The Microscope*, 59:4, pp 165–175) and, as the first few formed, matters soon became critical. A cascade of coagulation factors triggered the production of a forest of fibrin, and passing erythrocytes were mopped up in rapidly increasing amounts. They quickly became a vast clot of suffocating cells, cherry-black in color. Pressure built up until … disaster! The fatty mass tore free from its anchoring plaque and with a small but perceptible thud it rammed into the blood-vessel mouth and stuck there like a baseball down a drainpipe. Nothing could pass. The supply of blood to the heart muscle was switched off in an instant. A wave of anorexic pain roared through the nerves, and that is what caused the patient to rise from the pillow.

The heart responded immediately. It increased muscle activity in a vain attempt to boost fluid flow to compensate for the blockage. Fatal mistake. The metabolic effort led to the consumption of any remaining free oxygen, and the lactic acid overload stopped the heart beating. Without a continuous rush of dissolved oxygen, nothing could be done to move the muscle into motion and the heartbeat went crazily into fibrillation. The circulation stopped. The patient breathed his last.

The death of Clive Ewart was televised by Sky in 2008. Ewart was suffering from motor neuron disease and underwent assisted suicide in Switzerland. It is important to understand that, at the moment of death, his cells remained alive. Assisted suicide is becoming more widely accepted, and in 2014, Belgium passed a law allowing even children to opt for this end.

He may have seemed dead, but nowhere was he lifeless. When you apply my microscopical view, the situation looks very different. Hardly any of the cells in his body knew what was going on. They do not require much oxygen anyway because most don't live active lives. Follicular cells sit secure in the scalp, secreting slick slivers of keratin that are neatly laid in position to coat the shafts of new hair. They are like shakes on a roof, each upwards-projecting scale holding particulates in place so that unwanted matter is ratcheted upwards and away from the skin. This explains how a tiger can bathe in a mud pool and yet rapidly regain its brilliant white, orange and black with a few shakes of its fur. Grandfather hadn't washed his hair for a month; but because of this hidden mechanism, it remained as clean and fresh as a daisy.

It was much the same in the gut — the microvilli of the intestinal cells present such a vast surface area to what passes through that they take in the solutes and pass them on. They were still doing it even now the heart has stopped. They wouldn't even need to know that there was a heart. Around the throat and across the tonsils, phagocytes were still on patrol for pathogens and, here and there, groups were congregating to eliminate a clutch of staphylococci that were hanging about and bent on making trouble like drunks near closing time at a bar.

Macrophages, ever watchful for problems, were still drifting along on the waves of motion that bore them inexorably upwards, away from the lungs, and then pursuing a purposeful path that takes them downwards, against the flow, like a yacht tacking into the wind. Beneath them, lining the pathways that carried life-giving oxygen to the lungs, lay the glistening carpet of silky mucus propelled by the ceaseless beating of cilia in serried rows, tiny hair-like organelles that are not simply twitching like automata but arcing gracefully like rowers in boats.

LIVER OF LIFE

For the cells thronging in that great community of the liver, matters were now beginning to change. The word "liver" is a good name; these are the cells, more than any, that make us live. Most people assume that food is absorbed by the blood and distributed around the body, but that is far from the truth. All the food absorbed from the intestines passes into a single vessel (the hepatic portal vein) and is sent straight to the liver for processing. The cholesterol in the diet which seems to conspire to block people's arteries was not in the food that grandfather ate. It was manufactured by the hepatocytes, the cells of the liver. These are miraculous in sorting, metabolizing, detoxifying. Eventually they create what the body needs and methodically eliminate what it does not. Liver cells would laugh at our "detox" programs. Getting rid of toxins that build up in the body? There aren't any — our hepatocytes have seen to that.

A rush of fresh foodstuffs had been flooding into the lobules of grandfather's liver every second of his life and suddenly it had stopped. The liver cells have been among the busiest in the body and dramatically they have nothing to do. Most bodily heat comes from the liver. So active are the cells, perpetually oxidizing fuels and releasing energy, that the liver cells run at a high metabolic rate and would soon overheat if left to their own devices. The blood that courses through the 1,000 miles of tiny gaps between the clusters of liver cells carries the warmth away like a heat exchanger, much like the coolant in a nuclear power plant. The liver is the body's reactor, and its heat is what keeps us warm. In grandfather's body, the liver cells were scrambling to adjust, trying to optimize an impossible situation. They are doomed to death, though at this moment they are fully active.

Relatives stroking grandfather's hands think that his life is extinct, but how profoundly wrong they are. There is more frantic activity going on in his teeming

cell populations than has been manifested for years. This is emergency stations: pull out all the stops!

His son leans over and whispers words into grandfather's ear. "You old goat," he hisses softly. "I had you make me the beneficiary in your will. God, how I hated you!"

It was a quarter minute since he had officially died, and yet grandfather heard every word. He may even have wanted to move his fingers or blink his eyes, but no motor signals could be sent. The movements that grandfather could control at will — walking, smiling, sitting, looking around — were carried out by striated muscle cells that have a characteristic appearance under the microscope. They are nothing like normal cells, for they are marked by cross bands like steps on a ladder or the teeth of a zipper. My late friend Sir Andrew Huxley worked out how striated muscles function; his legacy still underpins our modern understanding. As a muscle contracts, those striped bands are drawn in, sliding against each other, to bring about muscular contraction, and these cells are consciously controlled. Is "cells" the right word? In voluntary muscle they merge together and lose their separate identity. These are muscle fibers, rather than discrete and recognizable cells.

Had you lifted the eyelids you might have seen that grandfather's pupils were still responding to light. Within 15 minutes, perhaps half an hour, the pupils would have become fixed wide open and staring. Fixed pupils? Dilated? Certainly they were. The cells of the ciliary muscles hold the pupils open and they were starting to go into spasm.

A third kind of muscle makes up the bulk of the heart. Cardiac muscle is also striated, but in a different way, and these muscles are not intended to be controlled by conscious will. They receive a regular impulse to contract in a carefully coordinated sequence. Cardiac muscle cells fork in branching and rejoining bands that have an easily recognizable structure under the microscope. Omit chopped heart from haggis, of which it an essential ingredient, and the microscopist can tell you without any problem at all. Should an unprincipled catering company add minced heart to boost the meat content of a beefsteak pie, and any seasoned microscopical observer will know in a minute. Grandfather's heart muscles were much as they were a minute ago, but since they were receiving no impulse to coordinate their contractions, they are now writhing pitifully and losing the will to live.

Grandfather had always been a devout Catholic though his daughter had rebelled against it. When she kissed him softly on the cheek for the last time, almost half a minute after he'd died, she whispered: "Even though you hated my choice of religion, dear old man, I always loved you and to think — now you'll never know it." Of course he knew it. He heard every word she uttered. As his consciousness faded from within, he found himself increasingly at peace. If this was dying, it wasn't as bad as he'd expected.

GUT REACTIONS

More than three minutes passed but grandfather's digestion was proceeding apace. Your intestines are always on the move. You think of them as a pink hosepipe, but in life they are squirming like squirrels squabbling in a sock. Grandfather's still were. Lay your ear against the naked abdomen of your partner and listen to the cacophony. It sounds like mud wrestling. The muscles in the intestinal walls are not consciously controlled. Like those that have your hair stand on end, or those that regulate your stomach and the pupils of the eyes, these are muscle cells without a sign of that cross-striation we encountered before. This is aptly known as smooth muscle, and this involuntary muscular tissue controls what goes on behind the scenes; actions the body takes every second of the day and night without our even knowing it. Your intestine moves, your hairs stand up or lie down, you shiver — much of the control of smooth muscle bypasses the brain altogether. Although the brain is the center of cognition and conscious control, there are areas throughout the body that have responsibilities of their own. The largest and most familiar is the solar plexus, a substantial concatenation of involuntary nervous control that lies deep in the abdomen.

As grandfather slipped further from conscious response, more than a minute after his final breath, he heard his last sound. His daughter shrieked: "He moved!" as his elbow gave a last tiny twitch, its shadow across the crumpled sheet amplifying the effect, showed how that involuntary muscle was responding to the great final shutdown. Throughout his body, cells were being starved of oxygen. But that didn't stop them living — because there was no gaseous oxidant they resorted to alternative metabolic pathways that began to build up a surplus of lactic acid. Grandfather was vaguely aware of discomfort, though his mind was way past caring. But deep in his body matters were serious. The cells of the liver were closing down almost completely, each cell plunging into hibernation. The body was no longer warming from within, and grandfather's temperature began, just perceptibly, to fall. It would gently settle down towards

room temperature, a slow decline that began a good 10 minutes later than everyone thought. As a student, I mused that the moment the fall in body temperature began could be said to mark the true time of death.

Our concept of the "moment of death" is nothing of the sort. Nothing has died. Grandfather has been a vast community of living cells all his life, and still he is. The ciliated membranes are slowing their rate of incessant beating, true; but still the cilia are beating. The cells within the parotid salivary glands are still secreting saliva, and a slow trickle slips from the corner of his mouth and glistens for a moment on his lips as if to prove the point. Had anyone at the bedside noticed, this would have been the last sign of life they'd have observed, for the saliva was freshly secreted and wasn't there when that final expiry of breath had taken place. It is 10 minutes since the doctor told the relatives that grandfather had died — and still he is alive.

But only just. Neurons had fought to adjust their metabolism to cope with a mounting burden of problems, but failed; one by one they shut down. In grandfather's lungs, leukocytes abandoned the struggle and many burst apart. Neurotransmitters were disappearing; the acidity balance was upset and the pH values had become intolerable in parts of the body, and these areas were beginning to spread. The progressive loss of smooth muscle tone meant his hands were showing faint signs of becoming grey, almost mottled; his cheeks had subtly sagged. A significant set of his cells were now beyond recovery. The cell community was fatally wounded.

DIFFERENT ENDINGS

That's the problem with a feather-filled comforter. It had kept grandfather snug and warm, just as the doctor advised. Had he drowned in freezing water, the lowered temperatures would have extended his cells' chances of survival to perhaps double the length of time it took in that cozy, warm bed. Shall we play with this line of thought? Let's do it.

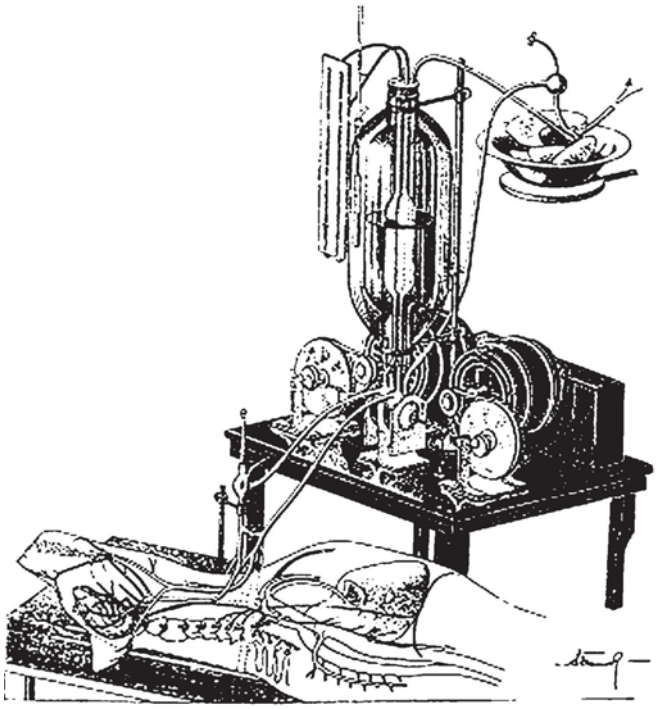
Suppose some quick-working, ingenious surgeon had slipped a sophisticated catheter into the femoral artery, up towards the aorta and — through a simple suction technique that I could sketch for you on a napkin — had seized the thrombus that had blocked the coronary artery and successfully withdrawn it; and she just happened to have a ready-charged defibrillator ready to shock the heart and re-establish the regular pulse; and assume for a moment that it all worked perfectly, then what would have been the result?

Life would have ended very differently. Administered shortly after his final breath, grandfather would have gasped, twitched, his eyelids would have flickered, and within half an hour he'd be propped up on his pillows and smiling. He would have turned to his son, winked slightly, and murmured: "You always were the best — stayed true to your religion, too. Not like some I could name. Bless you, my son." The surgeon would have patted his hand and told him to rest. And grandfather would reflect how wise he had been to leave everything to his son, a fitting heir and exactly the man to carry on the great family traditions.

Had it been after half a minute instead, history would have changed. The doctor would have had to shock grandfather's heart a second time before it began regularly to beat (we'll add a portable electrocardiograph to the miraculous equipment that the surgeon brought along). This time it would have been 20 minutes before grandfather opened his eyes, and an additional 7 minutes before he tried to speak. His son, ever attentive, would have leaned in to catch the words. "You bastard," grandfather would have hissed. At first, his son wouldn't have believed what he'd heard. Grandfather would hiss again, "You're taken out of my will." The surgeon would have raised her hand, not hearing what had been said but keen that grandfather should rest as he recovered. "Shall I call the priest?" she'd have asked. Grandfather would have shaken his head. "Call my attorney," grandfather would whisper. "My fortune will go to the Catholic church."

The story would have altered once more if, this time, we imagine that a full minute had elapsed. Although the heartbeat might have started again after the second shock, the surgeon would have instigated external cardiac massage by rhythmically pressing on grandfather's sternum, nodding as she counted the seconds. On the electrocardiograph screen, which had been so fortuitously hanging on the bedroom wall, the irregular heartbeat could have strengthened and — after a few ill-timed contractions — the normal waveform would have returned. Grandfather would have lain in a coma as time ticked by, then slowly he'd have opened his eyes and tried to focus in the gloom. Slowly he would have become aware of the familiar faces and he'd have smiled as his daughter leaned in. "Precious girl," he would have said. There would be a slight cough as his face contorted in discomfort, and he'd have rested back on the pillow, rewriting his will in his mind. The Methodist mission that his daughter supported would be the focus of his enthusiasms, and he now knew that she should inherit his fortune.

Let's extend the time even more. Had it been five



Sergei Sergeyevich Brukhonenko, a leading Soviet scientist in the 1930s, invented the "autojektor," the world's first heart and lung machine. Brukhonenko showed that the severed head of a dog could be kept alive using artificial circulation; he also drained blood from dogs — demonstrating them as technically dead — before reviving them. His published accounts of his autojektor used woodcuts to illustrate his papers (top). Blood was passed through a chamber where oxygenation could take place before being returned to the body. His ghoulish experiments with dogs generated interest in extra-corporeal circulation and eventually led to the bypass machines used in modern medicine. The severed head of one of Brukhonenko's experimental dogs (top left) could be seen to watch moving objects, blink its eyes and lick its nose. He showed that an artificial circulatory system would allow a head to survive long after being detached from its body. The most extreme experiments demonstrated that two heads (bottom left) could be maintained on one body. In 1959, Vladimir Petrovich Demikhov published accounts of removing the heads and forelimbs from Shavka, a 9-year-old bitch, and grafting them onto a stray dog they named Brodyaga (it means "tramp"). Both heads functioned after the operation.

minutes later, grandfather might have surfaced more slowly from his stupefied state with the vague memory of someone calling out. He could have made reasonable recovery, but would be plagued by disturbing dreams in which the staring face of his daughter (looking as if she'd been painted by Eduard Munch) loomed suddenly from nowhere and left him lying awake, sweating in anticipation and trembling with fear. He would have needed round-the-clock nursing, and much of his wealth would be consumed in the process; and when he suffered a series of strokes in later life he would have become a pitiful spectacle and died impoverished and unhappy.

Grandfather might have been revived later but he could well have been left partly incapacitated and emotionally traumatized. He may have become a disabled and dependent patient, and relatives who had been in the bedroom that fateful night would often think, in private moments, that it would have better if he'd been left for dead. Grandfather's wishes to change his will had come to naught, for his attorney knew that no new will could be relied upon when based upon a disabled man's uncorroborated and rambling ideas and the scrambled recollections that he insisted he could recall. His son was appointed to act on his behalf, and took command of the estate. Little money would be left for grandfather's medical care as he slowly withered away.

A CHILLING EFFECT

How different it would have been if grandfather had fallen through ice, instead of suffering a stroke in his bed. The sudden chill shocks the body into unconsciousness. The overstimulation of the vagus nerve would have rapidly shut down the body, thus preventing suffering, and the drop in body temperature would slow the metabolic rates of the cells almost to the point of dormancy. Under these conditions, cells in an apparently dead body can live far longer than people imagine. The medical texts give 40 minutes as the longest interval after which a hypothermic human can be revived, but this is far too short. There is a well-documented case of someone recovering after being clinically dead for four hours. She was a Swedish medical student named Anna Bågenholm. On May 20, 1999, she was skiing in the snowy mountains above Narvik, Norway. She lost control and smashed into a frozen stream head-first. It was 6:20 p.m. Only her feet and their skis stayed above the ice; she was trapped beneath eight inches of ice in running water at freezing point. Try as they might, her companions could not pull her out and after seven minutes of struggling they called the emergency services. As she twisted around, Bågenholm found an air pocket under the ice but her circulation shut down and, effectively, she soon died.

The rescuers set to work when they arrived and smashed a hole in the ice to pull her out. They lay her on a stretcher at 7:40 p.m. An hour and a half after the accident Bågenholm had no detectable pulse, no respiration, no circulation. Her pupils were fixed and dilated. Speak to doctors and they'll tell you: this was a dead person. Even so, they commenced CPR and kept it up until the rescue helicopter arrived. This took her to hospital, where she arrived, still lifeless, at 9:10 p.m. — almost three hours after crashing through the ice. The attending anesthesiologist, Dr. Mads Gilbert, said Bågenholm had a body temperature of 56° F, was gray and cold, utterly lifeless and with nothing showing on the electrocardiogram. Anyone would concur that Dr. Gilbert would have been entitled to regard the patient as dead. But he is a resilient and courageous individual, and he did no such thing.

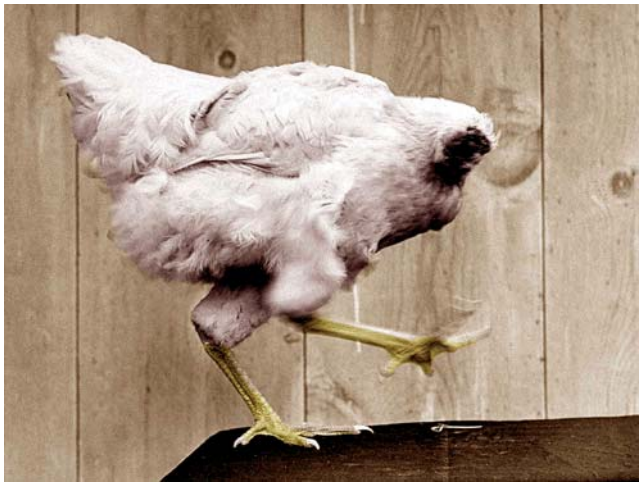
Gilbert is a highly motivated doctor who gained a postgraduate Ph.D. at the University of Iowa, worked on a kibbutz, and later wrote *Eyes in Gaza*. He always had an eye on cutting-edge medicine and, when faced with the lifeless body of Anna Bågenholm, he decided to assemble a medical team to restore her to life. More than 100 doctors and nurses, working in shifts, took nine hours to revive her. Dr. Gilbert decided to connect her immediately to a bypass machine that could restore her blood to body temperature. She was put on bypass at 9:40 p.m., and over an hour later, at 10:15 p.m., the monitors detected the first fleeting heartbeat. It was almost four hours after her accident.

Bågenholm awoke 10 days later on May 30 to find herself paralyzed from the neck down. However, her recovery continued, and she gradually regained use of her limbs. She took several months to recuperate, and although she was left with minor residual problems with her hands and feet, she became a radiologist at the hospital where her life was saved. We can argue about the length of time that Bågenholm was technically lifeless, but what certainly died that day was the traditional survival limit of 40 minutes in hypothermia. It has widely been claimed that the hemeproteins and energy-rich phosphates in the neurons run out of free oxygen a few seconds after circulation ceases. That could argue that this limits high-order cerebral function to a matter of minutes — but it doesn't mean that the brain is dead. Anna Bågenholm's extraordinary case suggests that the brain can survive for four hours, which throws a very different light on human sur-

vival after apparent demise.

Intense cold was also the key to the remarkable survival of an unnamed 15-year-old boy who stowed away in the wheel well of a Hawaiian Airlines aircraft in April 2014. The boy evaded airport security at San Jose International Airport, intending to fly to Africa. Instead, he climbed up underneath the Boeing 767 to Honolulu and squeezed into the small space after the wheel retracted. The plane flew for five and a half hours at a cruising altitude of 38,000 feet in temperatures around –50° C, with only a fraction of the levels of oxygen we experience at sea level. Like Anna Bågenholm, his body entered a state of suspended animation and he survived. Apart from raising questions about airport security, this can only inspire the followers of James Bedford, a psychology professor who was the first person to be cryogenically preserved on Jan. 12, 1967.

As a youth I used to see cowboys in the movies struck by bullets and falling lifeless to the ground, and I often wondered how frequently they regained consciousness when six feet under a mound of earth on Boot Hill. Television dramas remind us of the way our attitudes are changing. Look back to those black and white dramas and, as the patient flops back in bed, the doctor drops the wrist and announces the time of death. Now, when the patient droops and the cardiac monitor starts to warble, the doctor calls for the paddles, warns everyone to stand clear, and shocks the fibrillating heart back to action before sending the patient home again. People go on to live for decades, when — if the same event had happened a few decades ago — they would have been taken as dead.



This Wyandotte chicken was decapitated by its owner Lloyd Olsen in 1945. He had been asked by his wife to kill a hen for their evening meal, but this one survived and went on to tour the nation under the name of Mike the Headless Chicken. Mike died from choking on a meal, while being fed with an eyedropper, in 1947.

BRAIN DEAD AND HEADLESS

A unique accident in the Norwegian mountains may seem remote from everyday experience, but other cases pose crucial philosophical questions. Elaine Esposito of Chicago lay in a coma for over 37 years when she failed to awake from an anesthetic at the age of six. Sometimes she opened her eyes, and she continued to grow (weighing 85 pounds as an adult). She eventually died aged 43 years in November 1978 while being cared for in Pinellas County, Florida. Curiously, Terri Schiavo spent her final days in the same place; she would respond to people around her, and sit and move her eyes. She survived for 15 years in a semi-vegetative state after being found collapsed at home. Eventually, her family appealed for permission to have support withdrawn, so her feeding tubes were removed and she died in March 2005, 13 days after fluid and food had been stopped. At autopsy her brain was found to be discolored and scarred and had shrunk to half normal size. Video recordings available online show that Schiavo's visual coordination was maintained to the end, even though the autopsy revealed her visual cortex had degenerated. These cases make one aware of the possibility that apparently brain-dead patients could remain fully cognizant.

Much interest was shown in death and revival during the 1930s. In the Soviet Union, Dr. Sergei Sergeyevich Brukhonenko carried out pioneering research at the Institute of Experimental Physiology and Therapy in Moscow. He began his research in 1920, and by 1925 had publicly demonstrated his "autojektor" which was the first heart-lung machine. In 1940 the Scottish scientist Professor J. B. S. Haldane went to the Soviet Union to narrate a film on the experiments. In a dramatic experiment in the movie, a dog is exsanguinated and then, after a 10 minute interval, the blood is returned to the body and the dog shown to recover. Viewers are shown a beating dog's heart, maintained outside the body, and lungs that survived by being operated with bellows. Then the most gruesome experiment of all: The autojektor was used to keep a dog's head alive after being detached from the body. It blinked, licked its lips and looked around. Decapitation does not mean death. In those Russian experiments, the dog's head survived without the benefit of its body.

The opposite situation was exemplified by Mike, a chicken whose body survived without its head. In Fruita, Colorado on Sept. 10, 1945, a farmer named Lloyd Olsen was sent to bring a chicken for the pot. He beheaded a chicken with a glancing blow, chopping off its head while leaving a small part of the brain stem. After being decapitated, much to Mr. Olsen's surprise, the bird shook itself and strutted away. Finding the headless chicken still alive next morning, Olsen began to feed it with a dropper, and soon was exhibiting the chicken in touring sideshows under the name of Mike. The press became interested, and Mike was featured in *Life* and *Time* magazines. Press reports claimed that Mike was earning the Olsens the present-day equivalent of $50,000 a month at the height of his fame — until Mike choked to death in Phoenix in March 1947. This was the longest surviving headless chicken on record.

Cockroaches can also survive without a head, and it was discovered by the Victorians that, if you sever the spinal cord of a mating male frog, it keeps on mating. These disparate reports remind us that our notion of the "moment of death" is not in line with the realities of life.

THE FINAL CURTAIN?

Cells can continue to function many hours after a person has died. They say that the beard continues to grow so that stubble appears and, although this is true, some additional beard growth following the final breath is caused by the elongation of bristles due to the shrinkage of the skin after death. This allows more stubble to stand clear even though the hairs are little longer than they were. There are stories of hair growing long after death, notably those surrounding Elizabeth Siddal, who died in 1862. Her coffin was opened in 1869, and it was said that her hair had grown long after her death, filling the coffin with coppery-colored locks. This is either a foolish exaggeration, or it is a curious misinterpretation of a massive growth of fungal hyphae of the right color and with an appropriately wavy growth form.

And so we face the final curtain — when is life permanently and finally extinct? I do not know, and I am unaware of anyone who has set out to determine the answer. I have attended postmortem examinations and eventually amassed a large collection of preserved organs, including a leg amputated above the knee, several feet, some kidneys, a few hearts, the odd eye and a few excellent human brains — which, when fixed and sectioned many hours after death, showed the cells with perfect cytological structure under the microscope. I also know from my own hematological research that human leukocytes from the circulating blood can survive all night on a slide in the laboratory, and — were I obliged to make a wild guess — then perhaps four to six hours would be the time when life truly becomes extinct. As it happens, this is when *rigor mortis* sets in. This stiffening of the body is due to the contraction of the proteins within the muscles as acid degeneration ensues. It is, in other words, when the striated muscle cells have finally reached the end of the road. Meanwhile, the period immediately following the apparent death of an individual is a time when they remain — even if not respiring! — fully alive.

What about hanging? The end is brought about by the dislocation of the cervical vertebrae by the noose and the rupture of the spinal cord that lies within. Once this great nerve trunk is severed, then motor impulses cannot pass from the cells of the brain to the voluntary muscles. The body falls limp, and death is certified at that moment. On occasions, when the drop is insufficient or the weight of the prisoner too low so that the momentum generated by the falling body is insufficient to fracture the neck, then the hapless prisoner thrashes about at the end of the rope until they are brought to stillness by asphyxia. These episodes are regarded as tragic misfortunes and the death of the prisoner is remembered as a rare episode of when the quick death of a conventional execution is circumvented.

From the viewpoint I am advocating here — that of the living cells that comprise the body — normal hanging is little better for the victim. The snapping of the spinal cord certainly prevents the transmission of nerve impulses, so that agonizing movements of the limbs cannot be caused. It may make the heart falter and even stop beating, but it does nothing to kill the patient's cell community and does not prevent sensation and awareness in the brain. The hanged prisoner is fully aware of what has happened, and lacks only the ability to signal distress. The conscious activity of the cognizant brain soon fades, but for some time it remains. The prisoner is aware of what happens as they're cut down from the gallows.

The electric chair was seen as a humane alternative to hanging, but it did not always kill. Fred Van Wormer was electrocuted in the electric chair at New York State's Sing Sing prison in 1903, only to be found breathing in the morgue. He had to be electrocuted a second time to kill him. In 1946, Willie Francis screamed, "Let me breathe!" after being electrocuted on Gruesome Gertie in Louisiana. The voltage had been wrongly set and he survived. After appeals, he was sent to the chair

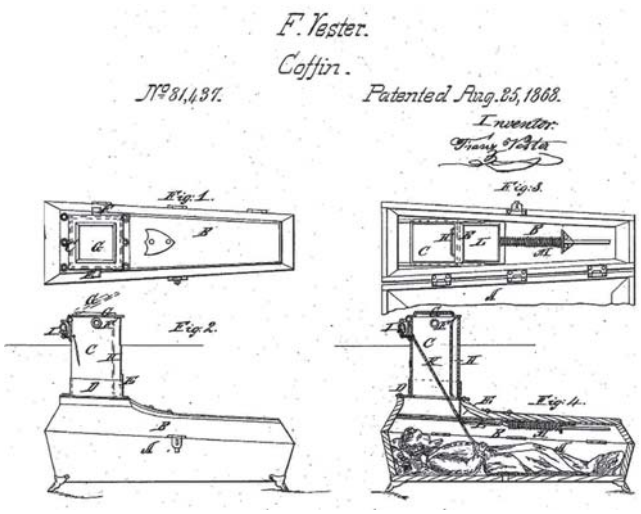
for the second time the following year. Lethal injection is also unreliable. Romell Broom was sentenced to death in 2009, but attempts to kill him were abandoned after the executioners failed to find a suitable vein. In January 2014, Dennis McGuire was said to have been "gasping for air" for over 10 minutes after being fatally injected. Three months later, Clayton Lockett's injections caused him to rise from the table in convulsions; he died of a heart attack almost an hour later.

SUICIDAL TENDENCIES

What of situations where people end their own lives? The suicidal sufferer, driven to distraction by the pressures of life and current preoccupations, may imagine — when they rush to the railroad and lay their neck upon the track — that the oncoming locomotive will end their inner strife in an instant. The train will certainly end their life, though not as quickly as people imagine. The wheels will sever the neck, and the detached head may bounce along the ties, but the victim may be looking back at the scene, watching as the train screeches to a halt a little way down the line.

It is impossible to tell when death supervenes, and for centuries people have feared being buried while still alive. The Victorians designed coffins fitted with a bell, so that someone who revived after being sealed in their casket could call for help.

This is not simply an old-fashioned idea. In 1995, an inventor named Fabrizio Caselli patented a safety coffin with an alarm, intercom, flashlight and cardiac monitor. Once in a while one still reads of people recovering after being certified as dead. There are cases regularly reported in the press. In Rio de Janeiro on Sept. 23, 2011, Rosa Celestrino de Assis was pronounced dead by the doctors and her body was sent to the morgue. Her daughter, Rosangela Celestrino, arrived some time later to take one final look at the corpse only to find it was faintly breathing. "I screamed out — my mom is alive! And they all looked at me like I was crazy," Rosangela said later. She wasn't crazy at all. Rosa wasn't dead. In 2012, Analia Bouter found her "stillborn" baby alive in the morgue at Resistencia, Argentina more than 12 hours after being certified as dead. In the same year, Lyudmila Steblitskaya of Tomsk, Siberia was found to be alive after three days in the hospital morgue; the autopsy was about to begin when she was seen to be alive. The family of two-year-old Kelvin Santos of Belem, Brazil, were mourning his death from pneumonia in June 2012. The funeral was about to start when the little boy sat up in his open coffin and asked for a glass of water. He then



Burial while alive gave rise to the development of "safety coffins" that were fitted with warning systems should the casket occupant revive. This example patented by Franz Vester in 1868 had a warning bell and cords for its operation. Such designs have modern counterparts — a safety coffin with a built-in cardiac monitor and intercom was patented in 1995.

lay down again and died. In January 2014, Paul Mutora of Limuru, Kenya, was heard calling for help 15 hours after being sent to the morgue for embalming. The next month, Walter Williams of Lexington, Miss. was pronounced dead by the local coroner but startled morgue workers the next morning by kicking out inside his body bag. The undertaker, Byron Porter, summed it up neatly: "He was not dead, long story short." Therein lies the problem — although Williams was not dead, the coroner had said he was. I advise you to ensure that your relatives check carefully before they let anybody sign that death certificate.

There are major lessons here for our understanding of humanity, for the nature of an individual at the end of life seen through my microscopical perspective leads us inexorably to some thought-provoking conclusions. The cessation of life of an entire organism does not equate with the death of the cells that comprise them and, after we have died, our cells are still living even if their coordination is fast disappearing. Metabolic processes continue to run. One second after we have diagnosed death, the cells in the body are as alive as they were one second before. Organs of sense do not instantly cease to function, and patients in a vegetative state may retain the ability to think, to hear and to see. The dying person is not as dead you thought they were. After death, we are still alive.