LETTER FROM CAMEROON

THE DOOMSDAY STRAIN

Can Nathan Wolfe thwart the next AIDS before it spreads?

BY MICHAEL SPECTER

"Look up," Nathan Wolfe barked. I didn't respond immediately, so the next suggestion came with an elbow to the ribs: "Take your head out of that map." We were standing on the side of "the road," a dirt highway that passes through the center of Mindourou, a dusty logging village in southeastern Cameroon. Wolfe, the director of Global Viral Forecasting, and several colleagues were in the midst of a ten-hour drive from the capital, Yaoundé, to a town called Ngoila, one of the many sites that G.V.F. has established in the past decade to monitor the emergence of deadly viruses from the jungles of Central Africa. He nodded toward a couple who had just pulled up beside us on a Chinese motorcycle. The driver wore flip-flops and a red tracksuit. His passenger, dressed in a pale-blue shirt and a matching pillbox hat, looked as if she were on her way to church. But that wasn't where they were headed. Her right arm was wrapped around the driver's waist. In her left, she clutched the lengthy tail of a freshly killed agile mangabey, a monkey often found in the lush forests of the region.

"Those monkeys are viral warehouses," Wolfe said to me, as the couple drove toward the market, dragging their bloody merchandise behind them. Mangabeys carry many viruses that infect humans, including one that may cause a rare form of T-cell leukemia and another, simian foamy virus, the ultimate impact of which is not yet known. Wolfe is a forty-year-old biologist from Stanford University; a swarthy man with a studiously dishevelled look, he comes off as a cross between a pirate and a graduate student. He is also the world's most prominent virus hunter, and he spends much of his time sifting through the blood of wild animals. "When I see a monkey like that dragged through the street, bloody, on the way to market, it's like looking at a loaded weapon," he said. "It scares me."

For much of the ride from Yaoundé,

Wolfe's world consists of "bacteria, parasites, and viruses"; animals are "a tiny little addendum." Photograph by Martin Schoeller.

Wolfe had been expounding upon the health dangers posed by bushmeat, the common term for tropical wild game, which includes monkeys, gorillas, chimpanzees, porcupines, scaly anteaters, cane rats, and other animals. Humans have subsisted on bushmeat for millennia, and in this part of Africa it remains a principal source of protein—sometimes the only source. Central Africans consume at least two million tons a year. It is not easy to convince somebody whose only alternative is hunger and malnutrition that eating monkeys or apes can be more of a threat to him than it was to his ancestors. Yet the health risks are enormous—not just for the Africans who kill and eat them but for billions of others throughout the world. If not for the consumption of bushmeat, AIDS, which has so far killed thirty million people and infected more than twice that number, would never have spread so insidiously across the planet. That pandemic, the most lethal of modern times, began nearly a century ago, in Cameroon, when a chimpanzee virus was transmitted to the blood of someone who almost certainly hunted, butchered, or ate it.

Deadly viruses have always threatened humanity, but a virus can travel only as far as the cells it infects. For most of human history, that wasn't very far. A few hundred years ago, if H.I.V. had passed from an ape to a hunter, that person would have become sick and died. He might even have infected his entire village, killing everyone around him. But that would have been the end of it. There were no motorcycles to carry the infected carcasses of slaughtered apes to markets in Yaoundé, and, for that matter, no airplanes to ship them to Paris or New York. Forests had been impenetrable for thousands of years. In the past few decades, however, new roads, built largely by logging companies, have brought economic opportunity to millions of Africans, along with better medicine, clean water, and improved access to education. Yet, seen from the perspective of a virus, those roads, combined with air travel, have created another kind of opportunity, transforming humanity into one long chain of easily infected hosts—no less vulnerable in California than in Cameroon.

Genetically, we are not an especially diverse species; an epidemic that can kill people in one part of the world can kill them in any other. "There is simply no greater threat to humanity than a viral pandemic," Wolfe told me. "What is more likely to kill millions of people? Nuclear war or a virus that makes the leap from animal to man? If, tomorrow, I had to go to Las Vegas and place a bet on the next great killer, I would put all my money on a virus." The Nobel Prize-winning molecular biologist Joshua Lederberg once expressed a similar sentiment, writing that viruses were "the single biggest threat to man's continued dominance on this planet." For most experts, the question isn't whether another deadly virus will appear, either naturally or from a lab in the form of a biological weapon, but when. "We cannot afford to let another epidemic like AIDS get out of control," Wolfe said. "Why are we sitting around passively waiting until new diseases infect half the globe?"

Wolfe compares the current approach to infectious epidemics to the treatment of cardiovascular disease in the nineteen-sixties. At the time, doctors could do little more than wait until heart-attack or stroke victims were rushed to the hospital, and then do their best to keep them alive. As our knowledge of factors like diet, smoking, and blood pressure deepened, the emphasis shifted largely from treating heart disease to preventing it. "When you know what the risks are, then your job is to lower them," Wolfe said. "And with viral epidemics we are beginning to know what the risks are. Yet, by the time we mobilize, it is invariably too late. Look at H1N1"—the 2009 influenza pandemic that infected as many as ninety million people in the United States alone and hundreds of millions throughout the world. "Since the strain turned out to be unusually mild, people said we made too much of a fuss. There was the sentiment—I have heard it expressed numerous times—that the public health service overreacted by trying to vaccinate as many people as possible. That's wrong. Wrong. Wrong. Wrong." Wolfe's voice rose half an octave with each word. "They did exactly what they should have done, and even that didn't help much. If H1N1 had been more virulent, it would have killed millions of people. Maybe tens of millions. Once it got out there, that thing burned right through the forest. We caught an amazingly lucky break, but let's not kid ourselves. Luck like that doesn't last."

Wolfe continued his soliloquy for much of the trip into the jungle—even after an unfortunate pit stop notable for a painful run-in with a column of red ants. To reach Ngoila, we had to cross the Dja River the only way possible: by ferryboat. Instead of an engine, however, the pilot relied on an elaborate pulley system and on the willingness of passengers to haul on the rope themselves. The crossing may well have been the highlight of Wolfe's week: he joined the tow line and guilted me into pulling, too. We made it to Ngoila as darkness fell.

After a restorative meal, Wolfe said it was time to look for bats, noting that they were among the most dangerous viral reservoirs on earth. At that, he and I marched into the pitch-black forest, accompanied by several members of his team and the thunderous honking of *Epomops* bats.

Most virologists spend their working lives in laboratories, looking at slides, focussing on specific proteins and, often, on a single disease. Nathan Wolfe's life conforms more to the pattern of a nineteenth-century explorer than to that of a twenty-first-century biologist. Instead of big game, however, Wolfe's trophies are viruses. A fastidious man who shaves his beard to a rough stubble every few days (and does the same thing to his head every few weeks), Wolfe has an office in San Francisco, where Global Viral Forecasting is based, and another at Stanford, where he is the Lorry I. Lokey Visiting Professor in Human Biology. He spends at least half his time in California but doesn't seem entirely at home there—unless the conversation turns to infectious diseases. Then Wolfe is all in. He can talk for hours about hemorrhagic fevers, river blindness, the Barmah Forest virus, and malaria—which, he will be happy to tell you, once nearly killed him. Wolfe finds the idea of the virome—the collective genetic structure

"His Highness is changing his relationship status."

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of every virus on earth—so captivating that he once described the world to me as a place that consists almost entirely of "bacteria, parasites, and viruses," adding that "animals really have to be seen as a tiny little addendum." The undergraduate seminar he teaches at Stanford each spring, on the ecological significance of microorganisms, is called Viral Lifestyles.

A few decades ago, Wolfe's microbial obsession would have been considered eccentric. The victory over communicable diseases seemed assured. In 1967, William H. Stewart, the Surgeon General, told a gathering of health experts at the White House, "It is time to close the books on infectious diseases." That statement was not wholly without justification. In the West, at least, polio, typhoid, cholera, even measles—all major killers—had essentially been vanquished. Smallpox, which was responsible for the deaths of more people than have died in any single war, soon disappeared.

Since then, however, at least fifty dangerous new viruses have passed from animals into humans. Some are so well known that their names are enough to make people anxious: Ebola, SARS, avian influenza. There are dozens of other diseases, like Lassa fever, brought on by a disabling hemorrhagic virus first discovered in Nigeria two years after Stewart's testimony, as well as those caused by the Nipah, Hendra, and Marburg viruses, which are less frequently mentioned yet just as frightening. These illnesses are called zoonoses—diseases that pass to humans from animals.

Wolfe is determined to break this pattern of disease transmission, which began ten thousand years ago, with the rise of agricultural communities and domesticated livestock. In 2008, with funding from Google.org, the Skoll Foundation, the Department of Defense, the National Institutes of Health, and others, he founded Global Viral Forecasting, with a goal that was both remarkably simple and stunningly ambitious: to detect pandemics as they begin and stop them before they spread.

Wolfe and his rapidly expanding team of researchers have created an extensive network of viral listening posts in the villages of Central Africa, and they have compiled a registry of viruses in many other places where pandemics often start: China, Malaysia, Madagascar, and Laos. In the past decade, the group has collected more than a hundred and fifty thousand blood samples from hunters and their families, as well as from the animals that they kill, butcher, and eat. The scientists screen the samples to determine whether any humans have been infected with viruses that came from animals. Virologists refer to the activity of viruses as they leap from animal to man as "viral chatter." Wolfe and his colleagues monitor samples for early warnings of an epidemic, just as, he often says, analysts "at the National Security Agency scour the Internet, listening for clues of impending terrorist attacks."

When Wolfe is in the field, he functions more as an anthropologist than as a biologist. The institute tries to keep track of hunters in scores of villages throughout Cameroon, the Democratic Republic of Congo, Gabon, and other countries. Outreach teams offer health-education classes and collect blood and tissue samples. This program, called Healthy Hunters, is pure social work. It isn't easy for a foreigner (or anyone else) to tell rural Africans how to conduct their lives. Customs vary widely. "On one of my first visits to a village site in Cameroon, I was with my ex-wife," Wolfe recalled recently. "When we arrived, the chief looked at her and asked me, '*Ça c'est pour moi?*' It took a second for me to get what he was asking."

The team tries to put local scientists out front and never to arrive in a village empty-handed. Before we left Yaoundé, Wolfe helped load a dozen soccer balls into the back of a Land Cruiser. It is virtually impossible to drive by a field in Cameroon without seeing a group of boys kicking something around—fruit, rolled-up wads of cotton, sometimes an actual ball.

Everywhere Wolfe and his colleagues go, they stress, in graphic detail, the critical point that primates are not for eating. They long ago learned not to push or proselytize. Hard sells backfire—and usually aren't necessary. In Central Africa, where people live in wattle huts and dine on bushmeat, viruses like Ebola and H.I.V. are not vague or distant horrors. They are present always, like an endless war, killing neighbors and destroying lives.

The institute's research has yielded disturbing results. In October, a group that included Wolfe published a report demonstrating that human parvovirus 4, which was thought to spread

solely through shared needles, is far more prevalent in sub-Saharan Africa than had previously been believed. Needles and blood transfusions couldn't possibly account for all the cases. More ominously, working with researchers from Cameroon and the Centers for Disease Control, in Atlanta, Wolfe discovered that the simian foamy virus, which is endemic in Old World primates, infects one per cent of those who come into regular contact with gorillas and other monkeys. That amounts to thousands of people walking around Cameroon with a retroviral infection that may or may not lead to illness. Before the study was published, the virus, which earned its evocative name because cells infected by it look foamy under a microscope, had never been known to pass between wild animals and hunters. None of the people infected with S.F.V. have shown signs of sickness. Yet, as H.I.V. has demonstrated, it can take years for a retrovirus to cause symptoms of a disease.

Wolfe hopes to create a database containing genetic information from those viruses, a resource that biological engineers could use to assemble effective vaccines from standard molecular parts. Building such vaccines, while a long way off, is a fundamental goal of synthetic biology. American bioterrorism experts have shown particular enthusiasm, though: any process that might protect humanity from natural viruses could also be deployed against viruses made by man. (This is just one reason that the Department of Defense and other federal agencies have been highly supportive of Wolfe's research.) "The more we learn about how these viruses are transmitted to humans, the more likely we will be able to stop them," Anthony S. Fauci, the director of the National Institute of Allergy and Infectious Diseases, said. "It is always better to prevent a disease than to treat it."

Detecting viral pandemics before they spread will be hard; responding to them before they spread will be harder still. "When it comes to understanding the origins of human diseases, you would be surprised how little we know," Wolfe said. "Where do the major diseases come from? How does a particular virus make the transition into a human host? Is it influenced by certain types of behavior or certain parts of the world? Why are some viruses so much more deadly than others? We have no answers for many of those questions." Even if scientists succeed in identifying new viruses before they escape into the wider population, pandemics won't disappear. "We know a lot about heart disease," Wolfe said. "But it still kills thousands of people every day."

Like snakes, viruses have a reputation as malevolent, poisonous, and deadly. In fact, most snakes are harmless, and dangerous viruses are rare. In order to inflict serious harm, a virus has to clear several biological hurdles. First, it has to remain unrecognized by the human immune system—to evade any protective antibodies. The virus would also need to make humans sick. (Most do not.) Finally, it would have to spread efficiently—for example, through coughing, sneezing, or shaking hands. Many viruses fulfill one of these criteria; some fulfill two; far fewer meet all three. "Look at H.I.V.," Wolfe said. "We would have to call that the biggest near-miss of our lifetime. Can you imagine how many people would already have died if H.I.V. could be transmitted by a cough?"

Viruses mutate rapidly, particularly in comparison with the glacial pace of human evolution. What seems benign one day can become deadly the next. Cold viruses are usually considered little more than nuisances, but SARS, a virus from the same family as many colds, is lethal. So is avian influenza. "When it comes to predicting what a virus will do, we don't even know what it is we need to learn," Wolfe said. "We are really just at the beginning."

He continued, "There was a moment in the nineteenth century before we had charted all the mammals in the world, and we found so many new species that people would say, 'Oh, gosh, we will never document the diversity of animal life on this planet.' And with mammals that now seems silly, because you would have to search your entire life to find a new primate. That early moment of discovery is where we are now with viruses. . . . I don't want to oversell it. But in theory, at least, the recipe is simple. You plug the dangerous viruses into some sort of vaccine pipeline. Get all the vaccine parts lined up, put them together, and get them to the people."

Wolfe's optimism is easy to embrace. Nonetheless, the barriers to achieving control over our biological surroundings are daunting. "I won't say viruses can be conquered," David Baltimore told me. Baltimore, the former president of Caltech, received a Nobel Prize for his work in elucidating the mechanics of retroviruses. "Not completely. But they don't have to conquer us, either."

The morning after we arrived in Ngoila, Matthew LeBreton, the ecology director of Global Virus Forecasting, stood in a laboratory in the back of the group's spare but well-equipped outpost. He slipped on a surgical smock, a pair of latex gloves, a face mask, and safety glasses. Then he picked up a live fruit bat and dangled it at arm's length. There are three dozen species of bats in southeastern Cameroon. LeBreton can identify all of them. Bats are well known for transmitting rabies, but they carry other debilitating microbes as well; fruit bats, for example, are believed to be the principal source of the Ebola virus. "The more you know about bats the more you are going to know about viruses," LeBreton told me as he laid the chocolate-brown specimen on a digital scale. "We try to process them carefully and often."

LeBreton took urine and fecal samples from the bat. He worked deliberately, but with speed, spreading the bat's wings and pricking them to obtain a blood sample, which he deposited in a vat of liquid nitrogen. He then turned to me and said, "Now we set the bat free."

Later that morning, we drove to Mbalam to watch Joseph Diffo, who was born in a similar Cameroonian village, discuss the dangers of bushmeat with local hunters and their families. Diffo has a master's degree in zoology

and has worked with G.V.F. as a wildlife technician since 2004. He serves as the site coördinator for field sampling and hunter-education programs. The hunters had gathered early, settling into couches and armchairs that they had dragged to the village square. Diffo, a husky man in blue work pants and a red checkered shirt, passed around a sheaf of photographs. The group suddenly became quiet.

"Do you see that boy?" Diffo asked, pointing to a recent picture of a local child whose face and body were covered with the type of blistering lesions that for centuries were the hallmark of smallpox. "Why do you think he looks like that?" Nobody answered—but any of them could have. "His father found dead monkeys lying in the forest," Diffo continued, speaking in French. "He brought them home to feed his family." At least one of those animals had been infected with monkeypox, which, while milder and less contagious than smallpox, can be deadly. "If you see a group of animals lying in the forest, do not pick them up," Diffo said. "Whatever killed them can kill you." It is a message that Diffo repeats constantly as he passes through the villages of Central Africa. He comes armed with gruesome pictures of dead primates, posters explaining the health dangers posed by hunting bushmeat, and bars of soap for people to use after killing or butchering their prey.

The audience was receptive; the repulsive pictures seemed to have an impact. Everyone collected a large bar of soap, and none of the questions the hunters asked were hostile, exactly. "What can you get us to replace this meat?" one of them asked. Killing primates may be dangerous for society and ecologically ruinous, but his children still needed to eat. "We don't have anything else to give them," he said.

Diffo cast a worried glance at Wolfe, who was watching from the side. "We know that," Wolfe said. "And we're working on it. But there is no easy way out."

Nathan Wolfe's first obsession was with chimpanzees. "I always loved them," he told me one evening, while we sat on the veranda of our hotel in Yaoundé, where his Cameroonian operations are based. "I spent years thinking about nonhuman primates, and there came a moment, in college, when I realized that, no matter how often we claim otherwise, humans are not the center of the world. We are players in a much bigger and more compelling drama. A lot of my work is just an attempt to figure out what that drama looks like and where, exactly, we do fit in."

In the early nineteen-nineties, while studying as an undergraduate at Stanford, Wolfe became interested in the self-medicating behavior of animals, and the fact that, as he later wrote, "not all pharmacists are human." Many species use plants as medicine in much the same way that we do. Kodiak bears routinely chew the root of *Ligusticum*, an herb more commonly known as bear root. They spit the juice onto their paws and massage it into their fur; researchers suspect it acts as an antibacterial agent. Birds also use plants as drugs, and they even appear to treat themselves with ants, in a procedure known as "anting," rubbing them vigorously through their plumage, until the ants secrete protective chemicals. (Wolfe's interest in self-medicating behavior is not wholly dispassionate. About a year ago, he switched from cigarettes to the Ploom—a high-tech nicotine-delivery system. To "ploom," one drops an aluminum pod of tobacco into the chamber of a Plexiglas cigarette holder that looks like it was designed for George Jetson. The Ploom delivers a measured, vaporized dose of nicotine, without tar or other cancer-causing chemicals. Wolfe loves to light up in restaurants and theatres, and since no

THE BLUE HAMMOCK

Behind the toolshed, among the nettles,
and rusting horseshoes, I buried the key.

The white dog watched me, whimpering,
as if he disapproved of what I was doing

but when I unearthed a bone and threw it
he bounded away, barking, into the field.

I replaced the spade in the shed, strode off
to the blue hammock, and climbed into it.

Swaying from side to side, I began to hum
the tune from the first spaghetti Western,

where Clint raises his poncho and shoots,
then lights up another cigarillo. Above me

the silver birch with my initials stretched
upward to its far-off father, the moon.

They would never, ever find that key, and
in the morning I would head for Lisbon,

where I'd rent a room in hilly Alfama,
then translate the entire work of Brecht.

The seagulls are huge there, and musical.
The crows spend most time on the ground.

—Matthew Sweeney

smoke escapes, nobody notices. "It's a total win-win for me," he said, between puffs on the strange device, which was invented by friends of his from Stanford. "Direct delivery of nicotine without the risk of death.")

Wolfe spent his junior year in the zoology department at Oxford, where he steeped himself in the theories of a longtime hero, Richard Dawkins, as well as in the work of other evolutionary biologists. After graduating, Wolfe began doctoral studies at Harvard, under the guidance of the British primatologist Richard Wrangham and the noted neuroscientist Marc Hauser. Wolfe intended to continue his exploration of the primate medicinal armamentarium, but Wrangham wasn't encouraging. "He said that learning how chimpanzees medicate themselves would make a perfectly interesting thesis," Wolfe recalled, "but to have an impact you are going to have to understand the underlying infectious diseases." Wrangham told Wolfe that he needed to become an expert in viruses and parasites.

Soon, Wolfe says, "I got completely hooked on viruses. It is an area of ecstatic ecological complexity." While in graduate school, Wolfe spent several summers in Uganda, where each morning he foraged for dead mosquitoes among the feces in gorilla and chimpanzee nests. "Not so glamorous," he said, shrugging. "But I was trying to find viruses in their blood. The idea was to get mosquitoes after they had had a blood meal. I think I got about five."

At the time, Wolfe was married to a social anthropologist he had met at Harvard. They argued energetically, but not in the way other people argue. "I was completely enamored with the idea that the best way to look at human behavior was to look at the behavior of animals," Wolfe said. "I believed in evolutionary psychology. She was a complete postmodernist." He forced the last two words out of his mouth as if they were razor blades. "We had fundamentally different views of the nature of human behavior. I would always say, 'At the end of the day, we are just animals with some nice frosting on top.' This drove her crazy. She was interested in how unique we are. The fights got pretty intense." Divorce may have been inevitable—but it took a while. First, she received a grant to study in Thailand, and Wolfe followed her, moving from Harvard to Borneo.

Wolfe's job there was to rescue orangutans that had become stranded in isolated parts of the forest where they could no longer survive. He would shoot the animals with tranquillizer darts, then move them to a reserve where they would be safe. Wolfe was also able to do research for his doctoral dissertation, on pathogens found in orangutan blood. "If you are trying to figure out what out there can infect us, then looking at apes makes a lot of sense," he said. "They have virtually the same physiology as humans—but live in these incredibly diverse terrestrial ecosystems. And they are up to their eyeballs in the blood of different types of animals."

One day, he received a message from his mother saying that an Army officer named Donald Burke was looking for him. Burke, the chief virologist at the Walter Reed Army Institute of Research, in Silver Spring, had met Wolfe at a public-health conference the year before, and the men had spent hours talking about their shared obsession with viruses. Burke's job, loosely defined, was to keep the United States Army safe from epidemics. For practical reasons, the military has always made the control of tropical diseases a priority. Malaria, for example, has often caused more sickness and death among soldiers than bullets or bombs have. In 1943, in the midst of the Pacific campaign, General Douglas MacArthur complained, "This will be a long war if for every division I have facing the enemy I must count on a second division in hospital with malaria and a third division convalescing from this debilitating disease!"

In the nineteen-eighties, Burke's studies of H.I.V. prevalence among military recruits were the first to provide a meaningful snapshot of the epidemic in the United States. The Pentagon wanted an AIDS vaccine urgently, and Burke was asked to direct the effort. He started by exploring genetic variations within the virus itself. As with many infectious agents, including polio and influenza, H.I.V. comes in several strains. A vaccine that will work for one will not necessarily work for all. Distinct regional variations are common: a single strain, for example, has been predominant in Europe and the United States, another in South Africa, and still another in Southeast Asia.

As Burke studied the data, however, he saw something remarkable. There was one place where every strain of H.I.V. could be found: Central Africa. "If you looked at Cameroon and Gabon, you would see the roots of the epidemic," Burke said. "But nobody had any idea why." Burke, who is now the dean of the school of public health at the University of Pittsburgh, decided to investigate further.

Virologists and medical anthropologists had long known that chimpanzees and other apes carry viruses similar to those which infect humans. That's hardly surprising, since those animals are our nearest evolutionary relatives. Still, nobody had made an explicit connection between the diseases of nonhuman primates and AIDS. "I certainly had never heard the word 'bushmeat' before I went to Cameroon," Burke told me. "Let alone the possibility that bushmeat was associated with the emergence of viruses."

Burke made his first trip in 1996, at the invitation of Colonel Eitel Mpoudi-Ngole, a warm, garrulous man who ran the country's AIDS program, and who was commonly referred to as Colonel SIDA—the French acronym for AIDS. "You did not have to spend much time watching people hunting chimps to understand that this was very clearly a possible route of exposure," Burke said. "There was blood everywhere, and no precautions taken by the hunters or their wives."

Burke and Mpoudi-Ngole selected fifteen linguistically and geographically diverse villages in locations across

Cameroon where they could test the blood of people who came in close contact with animals, particularly primates. It may now seem like an obvious undertaking, but essential ideas are often obvious only in retrospect. When I met Mpoudi-Ngole in Yaoundé, he told me that, by drawing attention to that link, Burke had done more to improve the health of Africans than had any other person alive.

Burke asked Wolfe to run the operation. Wolfe agreed, but told Burke that he wouldn't be free for at least a year. Burke said he would wait. "That may have been my best scientific decision," he told me, only partly in jest.

Wolfe lived in Yaoundé for five years, beginning in 2000, and says he loved every minute of it. He clearly feels at home there. Social skills are as important as scientific prowess to someone who spends so much of his life moving from one research outpost to the next, and Wolfe has a knack for management. He has been able to recruit prominent scientists who are devoted to him. "Nathan inspires me and he inspires everyone we work with," Joseph Fair, the organization's chief science officer, told me when I met with him in Yaoundé. Like others on Wolfe's team, Fair left a lucrative job to join the effort—and has never regretted his decision. "We work fifteen-hour days and on Saturdays and Sundays, and you do not get people to do that if they are not enthusiastic," he said. "Nathan makes people feel very good about what they do. Nobody leaves." (In 2008, Wolfe made a similar choice, walking away from a tenured position in epidemiology at U.C.L.A. to become a full-time virus hunter. "Try explaining that one to your Jewish mother," he said.)

We had come to Yaoundé to attend a meeting of military leaders and health officials from several Central African countries. The subject was pandemic preparedness. Wolfe, Fair, and the rest of the team were out every night, listening to West African music and eating tilapia, fufu, and cassava with friends and any number of Army generals. Wolfe was clearly the event's main attraction, and he was treated with deference by military officials

from Cameroon, Equatorial Guinea, Gabon, and Congo—people who rarely agree on anything.

"Hey, let's go look at some blood," Wolfe called, summoning me to what has to be the coldest laboratory in West Africa. The institute—a series of fortified bungalows—sits in the middle of a secure camp on the grounds of the Cameroonian Military Health Research Center, in central Yaoundé. It doesn't feel particularly military, though—or, for that matter, secure. Just a few hundred yards away, scores of merchants—who seem to have cornered the global market on extension cords, plug adapters, and USB chargers—sell their wares along the wide avenues of the capital.

The health-research complex has its own water supply, a liquid-nitrogen plant, and a series of freezers set at minus eighty degrees Celsius—an ideal temperature for preserving tissue specimens. Wolfe stood in the middle of a row of cylinders, each filled with cryogenically preserved samples of blood and tissue, taken from hunters, bats, cane rats, gorillas, spot-nosed monkeys, chimpanzees, and scaly anteaters.

Looking Californian in a maroon sport shirt and sneakers, he quickly unscrewed one of the cylinders. A gust of nitrogen vapor swirled out. The specimens in these containers make up perhaps the most comprehensive library of human and animal blood work in Africa. Hunters throughout the country now routinely carry filter paper, and when they kill a wild animal the hunters deposit a few drops of blood on the paper and seal it in a baggie (provided by G.V.F.). They can send the sample to the lab or wait until somebody comes to collect it. The idea arose from a method used by Matthew LeBreton to preserve dead snakes. "Everybody kills snakes. It is almost a reflex for humans," LeBreton told me. For years, he travelled the length of the country, compiling what would become the definitive book on the reptiles of Cameroon. "I would go to villages and ask people to just throw them in a pot of formalin, which preserved the snakes until I could collect and catalogue them."

Neither LeBreton nor Wolfe believes that it pays to be too picky about the specimens they obtain. "You do not wait for perfection," LeBreton told me. "When . . . we work with bats, we can get specimens into liquid nitrogen in the field. You can't get better specimens. They are frozen instantly. But it is critical for our work that we not wait for something to be perfect. Because it's never perfect."

The blood samples have already provided enough data for scores of scientific publications. Last year, scientists relied on the G.V.F. registry to identify the source of *Plasmodium falciparum*, the form of malaria that has probably killed more people than any other living organism. The origins and the evolutionary history of the parasite have always been murky. Because malaria is so widespread among humans, and so deadly, for years the most common scientific theory held that humans passed the disease to other primates. To test the hypothesis, Wolfe, Stephen Rich, of the University of Massachusetts, and others examined the genetic structure of a hundred samples of the chimpanzee version of the malaria parasite—*P. reichenowi*. They identified eight strains that collectively were far more genetically diverse than the human form. In fact, *P. falciparum* could, in most cases, be constructed from the genes of the chimp virus. That could only mean that the human form came from chimps, not the other way around.

Wolfe's team has also used its blood samples to search for variants of a virus called H.T.L.V.—human T-lymphotropic virus—which infects millions of people and causes leukemia and neurological illnesses. There had been two known strains—H.T.L.V.-1 and H.T.L.V.-2—and researchers found evidence of both viruses in the primate blood samples; they also discovered two new viruses, which they named H.T.L.V.-3 and H.T.L.V.-4. "This is an astonishing array of viruses," Donald Burke told me. "We have no idea how easily those viruses adapt to humans. Or how easily they can be transmitted between humans. But we better get prepared. Because, frankly, what we already know should be enough to frighten us all."

This year, Wolfe joined with a team of African, French, and American researchers to report a twentyfold increase in the incidence of monkeypox in Congo since the early nineteen-eighties. At first glance, the results were inexplicable. Then a pattern emerged: Vaccinia, the vaccine used so successfully to eradicate smallpox, also protects against monkeypox. After the last known case of smallpox occurred, in Somalia, in 1977, however, the virus was considered officially eradicated. In most countries, the vaccinations soon stopped, and when they did, a critical line of defense against monkeypox was lost. "The eradication of smallpox is one of the triumphs of medical history," Wolfe said. "But nothing in biology is simple."

Wolfe sat atop a freezer and dangled his legs like a schoolboy. The monkeypox finding was particularly gratifying to him because it demonstrated the unforeseen complexities of biological systems. "There is a thought experiment that I like," Wolfe said. ("Thought experiment" is a phrase he uses often.) "Let's just say you had a light switch on the wall and you could flip that switch and destroy every virus on the planet. Would you flip that switch? Almost everyone would say yes. But the effect on the planet would be so profound that life as we know it would cease to exist." Wolfe may be the viral world's most vigorous apologist, but he isn't wrong. Viruses can kill, yet they are also essential. In fact, vaccinia, which defeated smallpox, is itself a virus closely related to cowpox. In some parts of Japan, there have long been high rates of infection with H.T.L.V.-1, which can cause leukemia. People who are infected with that virus, however, are far less likely to develop stomach cancer than those who are not. In a study that followed a thousand people, participants were two and a half times as likely to develop stomach cancer if they were free of H.T.L.V.-1 than if they were infected.

Bacteria, the dominant life form on earth, are often controlled by viruses. They help regulate marine photosynthesis, and without them there would likely be no algae and no fish in the sea. In fact, earlier this year a team of researchers from M.I.T. managed to program viruses to mimic the process by which plants use sunlight to manufacture the chemicals they need to live. "The reason we think of viruses as neg-

ative entities is that physicians are the drunks looking under the lamppost for their keys," Wolfe has written. "If you are just looking for negative viruses, that is all you are going to find."

On a good day, a hunter in Messok-Messok, a dense jungle settlement not far from Ngoila, straggles home with an antelope slung over his shoulder. Or a cane rat. Monkeys, chimps, and gorillas are disappearing, so they are increasingly hard to find. But every so often somebody gets lucky. Late one afternoon, a village man walked into town carrying the body of a crowned monkey, which he turned over to his wife, a pregnant twenty-two-year-old named Sandrine. She laid the crowned monkey, so called for the soft tuft of white hair spread across its skull, on a mat of bright-green palm fronds that she had placed on the floor of the hut. Then she grabbed her machete. With practiced speed and impressive precision, Sandrine slit the monkey's gut, reached in, and pulled out its intestines. The ground was soon drenched with blood, and so were her hands. Wolfe, LeBreton, and I stood ten feet away, with several members of their team, who were wearing gloves and waiting to collect tissue and blood samples. As the young woman quartered the animal and sliced off its tail, the scientists pulled their face masks tight. I asked Wolfe if he ever offered such precautions to the villagers, and whether it bothered him to see this woman risk her life.

"Of course it bothers me," he said. "But here are the choices: We can do nothing. We can try to blend in and work without masks or gloves. I won't allow my people to take those risks. If you are asking if this is fair, then the answer is hell no. But it is not possible to get hunters and their wives to wear gloves. We try to convince them not to butcher if they have cuts on their hands.

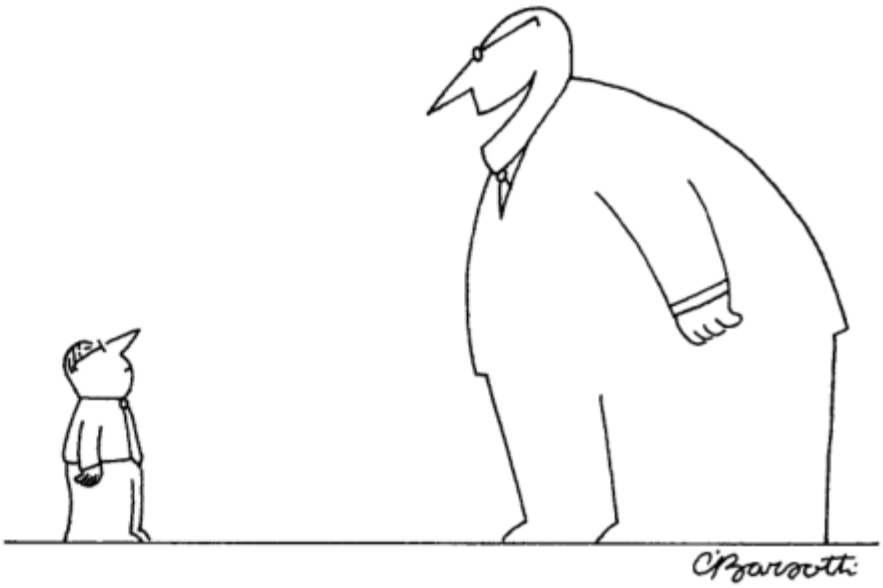
"The bigger question is what can we do for these people?" he went on. "How can we help them change their lives? Gloves are going to solve nothing. These people need economic opportunities and agricultural choices." (One of Wolfe's colleagues, a medical anthropologist, is working on just this issue. With support from U.S.A.I.D., she is attempting to determine the best way to change the behaviors that cause so much risk.) He pointed to Sandrine, who stood examining her work in the soft afternoon light. "She knows that this is risky," he said. "But it is not as risky for her as all the other choices in her life. We can worry all we want about viral pandemics, but that is not what keeps her up at night. She needs to care about dinner. And, until we recognize that, the rest means nothing."

There are no cell-phone towers in this part of Cameroon. No money. The best roads are mud paths cut by logging companies to move massive and ancient trees, some of which are so large that specially constructed trucks are required to cart them out of the jungle. Wolfe realizes that modern technology and globalization have connected viruses to humanity in dangerous ways, but he also sees in them an opportunity. "The forces that drove us into the age of pandemics can also help prevent them," he said. G.V.F. has started to focus on mobile communications—Wolfe considers the accumulation and analysis of "big data" a crucial advance for epidemiology. He recently hired a Stanford medical student, Lucky Gunasekara, who has a background in mobile technology. The team wants every hunter to have a phone. If somebody is feeling sick, or finds five dead gorillas in the forest, or if a doctor sees an unusual rash, a text message can get that information out at once. Viral listening posts won't work unless villagers are able to share their knowledge. "If Twitter can predict movie sales or stock-market movements, and Google searches can show us where the next flu outbreak will be, surely we can find tools to help this woman," Wolfe said. "If we connect these people more carefully to the larger world, we could begin to address many of these problems."

Sandrine had just finished preparing the meat for dinner. I asked her if she understood how risky it was to plunge her hands into the intestines of a dead monkey. "Yes," she said. "I know that bushmeat is dangerous. That it can kill my children." She was also aware that there had been an outbreak of Ebola recently in Congo. I wondered whether she or her husband had ever seen dead monkeys or gorillas in the forest. She nodded, gazing at the dark foliage as night began to fall.

"What did you do when you saw them?" I asked.

She turned to me and smiled. "I thanked God, picked them up, and brought them home for dinner," she said. ♦



"Don't be silly—mathematically, there will always be a middle class."