Small, Small World

They’re invisible. They’re everywhere. And they rule.

**By Nathan Wolfe**

**Breathe in. Feel the air pass through your nostrils and move into your nose. Your diaphragm contracts, pulling the air deep into your chest. Oxygen floods into tiny cavities in your lungs and travels into your capillaries, ready to fuel every cell in your body. You’re alive.**

So is that breath you just took. When we inhale, our nostrils capture millions of invisible particles: dust, pollen, sea spray, volcanic ash, plant spores. These specks in turn host a teeming community of bacteria and viruses. A few types may trigger allergies or asthma. Far more rare are inhaled pathogens that are themselves the agents of diseases, such as SARS, tuberculosis, and influenza.

Over the past 15 years I’ve spent a lot of time poking cotton swabs up human noses, pig snouts, and bird beaks, looking for signs of such agents before they cause deadly pandemics. As a result, I’ve come to think of air as the medium for the next pandemic rather than the means to sustain life. But breathe easy: Most of the microbes in the air do us little or no harm, and some almost certainly do us good. The truth is, we still understand very little about them.

We have known about bacteria, which make up much of the mass of life on Earth, only since Antoni van Leeuwenhoek began training his microscopes on samples of pond water and saliva some 350 years ago. Viruses—much smaller than bacteria but far more numerous than all other life-forms combined—were discovered not much more than a century ago, when people were already driving around in automobiles. And it is only in the past few decades that we have come to realize how ubiquitous microbes are, flourishing from the tops of clouds to miles below the Earth’s surface. We’ve just begun to understand how vital they are to our health and to the health of the Earth. We pride ourselves on having explored nearly every corner of this planet, but behind our world is a shadow world of microbes—and they are often calling the shots.

**Our past ignorance** of the microbial abundance on the planet stemmed in large part from our inability to grow most microorganisms in the laboratory. Lately DNA sequencing techniques have allowed us to study whole populations in a given environment without the need to culture any of them in a petri dish. In 2006, for instance, scientists at Lawrence Berkeley National Laboratory announced that air samples collected from San Antonio and Austin, Texas, harbored at least 1,800 distinct species of airborne bacteria, putting the richness of air in the same league as that of soil. Among them were bacteria from hayfields, sewage plants, hot springs, and human gums, as well as the oddly common bacteria found in deteriorating paint.

Many airborne microbes haven’t come from very far away, but some have traveled enormous distances. Dust from deserts in China moves across the Pacific to North America and east to Europe, eventually circling the globe. Such dust clouds harbor bacteria and viruses from the soils where they originated, as well as other microbes they pick up from the smoke of garbage fires or from the mist above the oceans they cross. Take a breath, and you sample the world.

Above the air we breathe, the upper atmosphere also contains microbes, floating as high as 22 miles above Earth’s surface. I believe they could go even higher, though it’s hard to imagine they could live long so far from water and nutrients. Lower down, they appear to survive and even thrive. There is evidence that despite high levels of ultraviolet radiation that would kill most bacteria, some metabolize and perhaps even reproduce inside clouds. In fact they may play a part in the formation of snowflakes that require a nucleator, or small particle, to crystallize around. In 2008 Brent Christner of Louisiana State University and his colleagues showed that microorganisms were the most efficient ice nucleators present in snow. That’s right—snow is literally alive.

Microbes don’t just inhabit the air—they created it, or at least the part we most depend upon. When life began on Earth, the atmosphere had no significant oxygen. Oxygen is a waste product of photosynthesis, and we owe the invention of that process, about two and a half billion years ago, to cyanobacteria. These bacteria are directly responsible for as much as half of the oxygen made on Earth each year and indirectly for most of the rest. Hundreds of millions of years ago ancient forms of cyanobacteria made their way into cells that would evolve to become plants. Once embedded in those ancestor plants, they evolved into chloroplasts, the photosynthetic, oxygen-producing engines of plant cells. Together, free-living cyanobacteria and their long-lost chloroplast cousins in plants carry out the vast majority of photosynthesis on our planet.

**But let’s get back to your nose.** Those airborne microbes you unwittingly inhaled? They’re just passing through. Your nasal passages also host a rich and complicated population of full-time residents. Three genera—*Corynebacterium, Propionibacterium,* and *Staphylococcus*—account for most of the bacteria in your nostrils. They form one community among the many that make up the human microbiome: the full genetic complement of bacteria and other organisms at home on your skin, gums, teeth, and especially in your gut.

All told, the microbes in your body outnumber your own cells by ten to one and can weigh as much as or more than your brain—about three pounds in an average adult. Each of us is thus both an organism and a densely populated ecosystem, with habitats harboring species as different from one another as the animals in a jungle and a desert. Even the resident microbes in the gum pockets around your teeth can vary greatly, suggesting, as David Relman of Stanford University puts it, that “each of our teeth is essentially an island, rocks in an intertidal pool.”

For the most part, the microbes inhabiting our bodies are either beneficial ones or unobtrusive freeloaders. They help us digest our food and absorb nutrients. They manufacture vital vitamins and anti-inflammatory proteins that our own genes cannot produce, and they train our immune systems to combat infectious intruders. Resident bacteria on our skin secrete a sort of natural moisturizer, preventing cracks that could allow pathogens to penetrate.

As we learn more about the relationships between ourselves and our microbes—and their own complex relationships with one another—scientists are coming to see the microbiome the way ecologists have long viewed an ecosystem: not as a collection of species but as a dynamic environment, defined by the multitude of interactions among its constituents. This should mean greater care in the use of antibiotics and, increasingly, targeted probiotic treatments that don’t just temporarily boost the numbers of one microbe or another but that shore up the whole population so that our health is improved. “We know how to disturb a community,” says Katherine Lemon, a microbiome researcher at the Forsyth Institute in Cambridge, Massachusetts, and a clinician at Boston Children’s Hospital. “What we need to learn is how to coax it back into a healthy state.”

This perspective on our relationship with microbes—as fellow travelers to be cared for and managed to our benefit—is a far cry from my day-job view of them as killers to be hunted down and eradicated before they can spread. Both views are valid, of course. We should never let our guard down against the threat of infectious pathogens. But as we continue to explore the microbial world, our fear of the invisible beings around us, and in us, should be tempered with respect for what we are learning about them—and a rush of excitement for what remains to be discovered.