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EVEN SUPERHEROES NEED HELP SOMETIMES: THREE INCREDIBLE TALES OF MICROBIAL SYMBIOSIS

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Whether you are looking at a crowded city, a remote desert, or deep down on the ocean floor, you will find living things interacting with each other. When an interaction continues for a long time, it is called symbiosis. Here, we explore three different examples of symbiosis told using superheroes! We will first dive into the ocean and tell you the story of a squid that has the superpower to light up like a flashlight in the dark. We will then travel up into the trees of Australia where you will meet superhero sidekicks that help their furry koala friends digest poison. Finally, be prepared when we meet a villain that is threatening frogs around the world. What makes these examples special is that one of the living things in each symbiosis is so tiny that we cannot even see it without a microscope! These organisms, called microbes, are just as important as the animals and plants that we can see.

SUPERHEROES, SIDEKICKS, AND VILLAINS

Imagine you want to write a superhero comic. Obviously you need the superhero, the star of the show. But what else do you need? How about a sidekick, someone who helps the hero out? What about people to save? Maybe an evil villain to fight?

SYMBIOSIS
The close and long-term relationship between two or more organisms.

MUTUALISM
A type of symbiosis in which both organisms benefit from their interaction.

COMMENSALISM
A type of symbiosis in which one organism benefits, but the other is unaffected by their interaction.

PARASITISM
A type of symbiosis in which one organism benefits, but the other is harmed by their interaction.

MICROBES
Tiny living things, like bacteria and fungi, that are invisible to the human eye.

In biology, the relationships between the superheroes and each of these characters (a sidekick, people to save, and a villain) are called "symbioses." Life on earth is full of symbioses of different kinds, and we can see them anywhere we look. Can you think of any right now? For the superhero and the sidekick, who always watch each other's backs, we call this type of **symbiosis** "**mutualism**," which is a fancy way of saying "helping each other." When the superhero saves someone in trouble, this type of symbiosis is called "**commensalism**," and only one of the two people benefits. When villains harm others, while only helping themselves, this type of symbiosis is called "**parasitism**."

We are constantly interacting with other organisms. These interactions include our families, teachers, friends, and pets. They also include the trillions of invisible living things, called **microbes**, that live in and on our bodies. We never notice most of these microbes, but they live on every surface around us. Some of the microbes make our lives easier (sidekicks) while others can make us sick (villains).

Now we are going to introduce you to three superheroes and explore their relationships with the microbes living around them (Figure 1). The first example describes an exciting mutualism where the superheroes and their sidekicks team up to be lights in the dark. Then, we will give you an example of microbes living inside an adorable Australian animal—the koala bear. Most tummy microbes just hang out there and nobody ever notices—a typical case of commensalism, but we are also going to introduce you to one little microbe in the tummy that can help koalas eat poison! Our parasitism example, which involves a terrible microbe that swims in freshwater trying to kill frogs, will definitely give you the chills. Do not worry though, there is a new sidekick on the scene who can help frogs defeat this evil villain.

ARE YOU AFRAID OF THE DARK? SQUID ARE TOO!

Imagine having a built-in flashlight that you could turn on when you are scared. That is what life is like for the Hawaiian bobtail squid, *Euprymna scolopes*, but instead of a flashlight the squid has an organ on its belly that is home to a glowing microbe called *Vibrio fischeri* [1]. The squid can tell the *Vibrio* in the organ to light up, just like pressing a button to turn on a flashlight. Can you think of a good reason why the squid would want to do this? Scientists have figured out that the squid do this to avoid becoming a midnight snack!

FIGURE 1

The symbioses of three superheroes. Here we can see our three superheroes (squid, koalas, and frogs) interacting with their microbial friends and enemies (numbered above). Blue arrows indicate the organism that benefits from the relationship (commensalism or mutualism) and red arrows indicate the organism that is hurt (parasitism).

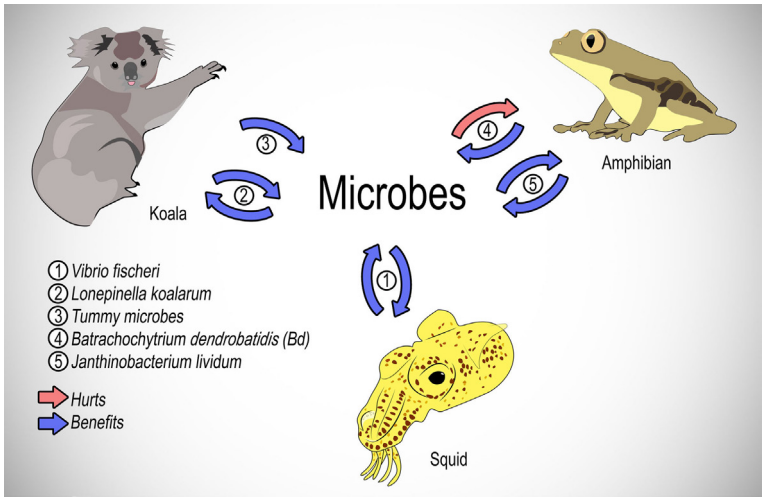

FIGURE 1

When the squid turns on the built-in flashlight in its belly, large hungry sea creatures looking up from the depths will think that the light from the squid is the moon. Hungry critters looking down from above will see nothing because the light from the *Vibrio* causes the squid to have no shadow. By glowing like a flashlight, the *Vibrio* are essentially giving the squid the power to become invisible! This relationship between the squid and the glowing *Vibrio* is what scientists call mutualism, which is just another way of describing real life heroes and sidekicks. The squid and *Vibrio* both get a good deal! The squid now has the power to hide from the scary creatures that want to eat it and the *Vibrio* gets a cozy place to live and all the food it wants by living inside the squid's light organ.

You may now be wondering, how did *Vibrio* become the squid's sidekick in the first place? Squid are not born with their glowing sidekick, so they have to search through all of the microbes in the surrounding seawater to find them. They catch *Vibrio* in a special snot-like trap on the outside of their belly that also serves to keep out other microbes that could be villains. Once the squid finds its sidekick, the glowing *Vibrio* will move from the snot-like trap into the light organ in the squid's belly where it will help keep the squid invisible to the villains awaiting in the deep.

POISON FOR DINNER? YES PLEASE!

Could you imagine eating the same food for your whole life? How boring! Now imagine if that one food were poisonous? Yuck! Koalas do exactly that; they eat the leaves of a tree called *Eucalyptus* every day. *Eucalyptus* trees have poisons in their leaves that prevent most animals from eating them, but not koalas! Now that is a cool characteristic of a superhero! But how can they

survive on nothing but poisonous leaves? Well, it turns out there are special microbes in the tummies of koalas that work really hard to break down the poisonous parts of the leaves into smaller pieces that cannot hurt the koala. Most of the microbes in the koala's tummy are just hanging out, a good example of commensalism. This means that these microbes are not helping break down the poisons, but they are not hurting the koalas either. One microbe that can break down the leaves, *Lonepinella koalarum*, is an important poison-fighting sidekick and forms a mutualism with koalas [2]. Scientists are still learning about these microbes that serve as sidekicks to their koala superheroes.

Lonepinella and other potential poison-fighting microbes in the koala's tummy are so important to koalas' survival that the koalas give these microbes to their babies. How? You guessed it! The babies eat poop! Ewwwww gross! This happens when a baby koala, called a joey, is still very tiny and living inside the mother's pouch. The joey crawls out of the mom's pouch to eat a special poop. Scientists believe the reason why joeys do this is to get all of the toxin-fighting sidekicks from the mom's poop. The microbes in mom's poop move into the joey's tummy, set up home, and get ready to work!

IS A VILLAIN LURKING IN A POND NEAR YOU?

Have you ever gotten an infection in a cut on your skin? Infections on your skin start when certain microbes decide to grow on you and would not let you heal! Even though most microbes do not cause problems for animals and plants, there are some microbes that act as villains in nature. One example, a microbe that attacks **amphibians** on their skin, causes them to get sick. The microbial villain in this relationship, also known as *Batrachochytrium dendrobatidis* (*Bd* for short), swims around in lakes and streams until it finds a frog or salamander and attaches to its skin. This is an example of parasitism, because the amphibians are harmed while the villainous microbe gets to grow and reproduce. Amphibians use their skin to breathe and absorb important nutrients, so when *Bd* grows all over the skin it weakens the animal and it begins to suffocate. The animal will try to fight back by shedding its skin and releasing substances in the mucus layer on its skin, however, this is often not enough to get rid of the villain [3].

AMPHIBIANS

A group of animals including frogs and salamanders that typically spend part of their life in water and part on land.

The sickness induced by *Bd* has killed off tons of amphibians around the world, and the death of amphibians affects all of us. If all of the frogs and salamanders disappear, then the earth will be in big trouble. For example, amphibians eat a lot of insects, such as pesky mosquitoes that can become a real problem if there are too many of them. This is just one reason it is important for scientists to figure out how to help save the amphibians before *Bd* causes even more frogs to disappear.

RECRUITING NEW SIDEKICKS FOR THE BATTLES TO COME

Scientific research has helped us to learn about microbes that can act as sidekicks to protect us from villains. For example, the microbe *Janthinobacterium lividum* helps protect amphibians from *Bd*. Amphibians use substances on their skin to keep off certain microbes and to encourage the growth of sidekicks like *J. lividum*. This provides *J. lividum* with a nice and nutrient-rich place to live. In return, *J. lividum* can provide benefits for the amphibian. One benefit of *J. lividum* is that, when it battles with *Bd* on the amphibian's skin, it kills *Bd* and saves the animal from getting sick [4]. Could we save amphibians by introducing more superhero sidekicks to their skin? Maybe! There are many scientists trying to figure this out right now by studying the battles between heroes and villains and the important role that sidekicks play. Scientists can use their knowledge of symbioses to help keep plants and animals (including us!) healthy.

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Laetitia Wilkins is a research scholar from Switzerland. She is fascinated by relationships between animals and microbes that are very old, and she wants to learn how microbes helped their host animals survive. She gets to visit wild places for fishing and diving, but sometimes she also has to spend weeks in a fridge to run experiments. Her partner and two children usually accompany her during her adventures. She cares about diversity and critical thinking and she is helping researchers with families to thrive in academia.

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Jonathan A. Eisen is a Professor at the University of California, Davis and is a bit obsessed with all things microbial. He worked on microbes as an undergraduate at Harvard College (on beneficial symbionts of clams and tubeworms), as a Ph.D. student at Stanford University (on evolution of microbes, especially those from extreme environments) and in his current and past faculty appointments (on communities of microbes, how they interact with each other and hosts, and methods for studying such communities). He also is an active and occasionally award-winning blogger and science communicator.

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David A. Coil studies microbes at the University of California, Davis in the laboratory of Dr. Jonathan Eisen. He got his Ph.D. in 2005, studying how viruses enter cells. Since then he has worked on bacterial villains and a wide range of interesting microbes from cool places, including cat butts, hummingbirds, seagrasses, and the space station. David is particularly interested in education and communicating science to the public.