Outbreak: Orangutan's mysterious death points to threat of diseases that jump to humans

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On a frigid night a few days after Christmas 2012, Trish Khan drove back to the Milwaukee County Zoo to check on the star attraction, a playful, wildly popular 5-year-old orangutan named Mahal. It was almost 11 p.m.

Khan, the zoo's primary orangutan keeper, was off on medical leave. Yet she'd come in earlier in the day, as soon as she heard something was wrong with Mahal.

Raised on a horse farm in Wisconsin, Khan has a passion for animals, especially primates and most especially orangutans, a great ape found in Asian rainforests and admired for its intelligence.

Even so, her deep affection for Mahal was unique. She had flown to Colorado to pick him up from the Cheyenne Mountain Zoo after the orangutan had been rejected by his mother. Khan had accompanied Mahal to Milwaukee, and when he settled in at the county zoo, she bottle-fed him for the first year.

When Mahal was sick, she would move a mattress into the enclosure and stay with him, allowing him to nest beside her and sleep until morning.

Four years later, as she examined the orangutan on that winter evening, Khan noted how much he resembled a sick human child: no energy, no

appetite. After an unsuccessful attempt to administer antibiotics, Khan and one of the zoo veterinarians decided to move the orangutan into a smaller room and wait until morning to anesthetize him and take blood samples.

The next morning, a zookeeper found Mahal lying motionless on the floor. He was dead at just 5 years of age; the typical orangutan lives 35 or 40 years in the wild and sometimes more than 50 in captivity. In his short life, Mahal had been the subject of a newspaper series and a children's book.

Stunned as they were by the loss, Khan and her colleagues now faced a mystery with implications for both animals and humans: What killed Mahal?

"Is it something that could affect our other orangutans or other animals?" Khan remembers wondering. "Is it something that could affect our keepers?"

The similarities between humans and other primates are well-known. It is the reason monkeys have long been used in medical tests as proxies for humans. It's also the reason the zoo regularly consults with doctors at Froedtert Hospital on health problems involving its great apes.

But the close biological relationship between the two species takes another form as well. Lethal diseases, including Ebola and HIV, have jumped from apes to humans. Others, such as influenza and polio, have gone the opposite route, passing from humans to apes.

"When you're dealing with the great apes," says Khan, "pretty much anything they get, we can get."

And therein lies the problem. The zoo could not simply mourn the loss

of Mahal and dispose of his remains. Other lives were at stake, including those of the zoo's 45 other primates and the seven employees who cared for them.

Of the 400 or so emerging infectious diseases identified since 1940, more than 60 percent have been zoonotic, meaning they have passed from animals to humans.

A 2012 report by researchers in Britain, Kenya and Vietnam found that each year zoonotic diseases account for 2.5 billion cases of human illness and about 2.7 million deaths. A separate study published the same year put the direct costs from these diseases at more than $20 billion over the previous decade.

Zoo officials in Milwaukee were not taking any chances. Within hours of his death, Mahal's body lay in a cooler packed in ice, bound for a pathologist's lab at the University of Wisconsin-Madison.

So began an investigation that would span more than three years and lead to the discovery of a new species of pathogen. The search for Mahal's killer also would illustrate the links between diseases and some of the most powerful forces on the planet: evolution, glacial periods and the Earth's orbital patterns, known as Milankovitch cycles.

"The fact that we share so many diseases with primates tells us about evolution," explains Tony Goldberg, the UW professor of epidemiology who led the investigation into Mahal's death.

"There are an awful lot of primate pathogens that don't really care whether they're in a human or a chimpanzee or an orangutan."

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Like all great apes, orangutans face health challenges in captivity. Males are more susceptible to urinary tract infections than they are in the wild; it's uncertain why. Many great apes also suffer from heart disease.

Neither illness seemed likely given Mahal's youth.

The orangutan's body arrived at the University of Wisconsin lab of Annette Gendron, a veterinary pathologist who'd worked in Kenya for a year and later at the Fresno Zoo before coming to Madison in 1983. In more than 30 years as a pathologist, she'd performed necropsies on everything from great apes and elephants to snakes and giraffes, "almost anything you can think of."

Following protocol, Gendron and zoo pathology resident Kathleen Deering each dressed in a protective gown, a double set of gloves, a mask and face shield. Necropsies - autopsies performed on animals - take hours and it is all too easy for pathologists to spatter themselves with material from the dead animal.

Once, 40 years ago, Gendron was accidentally exposed to the fungal lung infection Valley fever, while helping veterinarians try to resuscitate an orangutan before it died. On another occasion, one of her gloves leaked while examining the intestines of an antelope and she wound up with an infection under her fingernail.

Although she never became seriously ill, these incidents reinforced her cautious nature.

Gendron began her examination of Mahal by taking measurements, noting the size of the orangutan's pupils and searching for skin lesions, evidence of trauma and discoloration of the membranes of the mouth.

Then she cut open the orangutan's body. There was no fluid in the

abdomen. Fluid is often a sign of inflammation, which in turn raises a host of possibilities, from tumors to liver or kidney failure.

One by one, Gendron looked at the organs. First the spleen, then the liver, kidneys, adrenal glands, heart, lungs and trachea. She removed and weighed each organ and looked for scarring and abnormalities. She placed tissues from all of the organs in formalin, a preservative that would allow her to view them later under the microscope.

Although the pathologist worked methodically, she had noticed something strange from the very beginning.

Mahal had an enlarged spleen and liver. Both organs were overrun with cysts, small gray bubbles.

"There were enormous numbers inside the liver," Gendron says. "We'd never seen anything like this."

Whatever it was, the pathogen had also clogged Mahal's lungs. The official cause of death was acute respiratory distress syndrome; what it meant was that the orangutan had essentially drowned in his own blood.

The necropsy took between four and five hours. When she was finished, Gendron made microscope slides of tissue from the nerves, heart, lungs, brain and other organs.

Over the next few weeks she sent zoo pathologists around the country a digital photo of one of the cysts from Mahal's liver. She hoped specialists who'd examined great apes might have run into something similar.

No one had.

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One of the colleagues Gendron contacted was Goldberg, a fellow member of UW's faculty of veterinary medicine.

Goldberg, who had started out studying hummingbird behavior at Amherst College in Massachusetts, had gone on to focus on primates while earning his Ph.D. at Harvard. He joined the UW faculty in 2008.

Over the last decade, Goldberg had flown to Uganda twice a year for up to a month of fieldwork examining the interactions of people, primates and other animals in and around Kibale National Park.

The fieldwork often reminds him how much the world is changing, and how quickly new health threats can cross from species to species, continent to continent. For much of the world, the Zika virus, named for the forest in Uganda where it was discovered, stands as the prime example.

Spread by the Aedes aegypti mosquito and first discovered in a rhesus macaque in 1947, the virus appeared in humans in Uganda and Tanzania in 1952. However, in the last two years, the virus suddenly spread through large sections of Central and South America. In July, the U.S. recorded its first homegrown cases of the virus in Florida. By December, Zika had been identified in 75 countries and territories.

But Goldberg can point to a more personal example of today's rapid-transit pathogens. In the summer of 2012, just six months before Mahal died, Goldberg had returned to Madison after working in western Uganda. He'd been home only three days when the dull ache he'd detected in his nose flared into a searing pain, impossible to ignore.

By angling a mirror and contorting his body, the scientist was able to

peer inside his nostrils. There it was, just as he'd suspected: the pale, fat back end of a fully engorged tick.

"It took all of my willpower not to claw off my face," he would recall.

Instead, Goldberg gently extended a pair of forceps until they surrounded the tick's mouth, then he pulled firmly, but carefully. Out came a creature about the "diameter of a pencil eraser," he recalls, "really nothing more than a distended stomach."

DNA testing revealed it was a new species of tick, a discovery that, in the scientist's view, far outweighed his discomfort. Somehow the tick had crawled onto Goldberg's body in the Ugandan forest and stowed away inside his nostril through the plane trip to the U.S. The scientist's reward was a paper he co-authored titled "Coincident Tick Infestations in the Nostrils of Wild Chimpanzees and a Human in Uganda," published in the American Journal of Tropical Medicine and Hygiene.

But it wasn't Goldberg's tick discovery that made Gendron think of him for the Mahal investigation. She recalled his recent paper on hepatocystis, a single-cell parasite transmitted by midges.

Could the cysts inside Mahal be hepatocystis?

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There's just no love for the lowly parasite.

The shark is more frightening, the naked mole rat uglier, the black mamba snake deadlier. Yet few creatures provoke a more visceral shudder of disgust than lice, tapeworms, mites and the various other organisms known as parasites.

After his close encounter with the tick, Goldberg understood why.

Still, years of research had tempered his reaction. "You wind up having a lot of respect for parasites," he says. "They are very clever."

They have to be. To keep living, parasites must depend upon another organism, or host. They employ finely tuned machinery to infect and stay in the host without being detected and killed off by the host's immune system.

Parasites are master survivors. They have been around much longer than humans, likely as long as there have been living organisms, according to Eric Hoberg, former curator of the 120-year-old U.S. National Parasite Collection, among the world's largest repositories of different parasites.

Although it's not known how many parasites share the earth with us, one estimate puts the number of different helminths, or intestinal worms, at between 75,000 and 300,000. All told, more than half of the organisms on the planet are parasites, from the microscopic bacterial cell to the multicellular tapeworm.

Many have evolved clever tricks to find the right host, survive and spread. Take the wily Toxoplasma gondii, a single-cell parasite that starts by infecting a mouse but must enter a cat in order to reproduce. To go from mouse to cat, Toxoplasma gondii disables the rodent's ability to smell cat urine, essentially leading the mouse into the jaws of its enemy.

Of greater concern to humans is the Guinea worm. The worm's larvae develop after being consumed by water fleas; they then infect humans who drink the flea-infested water.

Once inside the human body, the worms grow to 2 or 3 feet in length, until the female worm causes a burning sensation so extreme it drives the

human to seek relief by submerging the infected area in water. The worm's offspring are then released from a skin blister into the water to continue their life cycle.

The sheer number of parasites can make identifying them difficult, and as Mahal's death would show, there is still much we don't know.

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Goldberg crossed busy Campus Drive and proceeded to Gendron's UW lab to collect samples of Mahal's liver, lungs and spleen. All were securely stored inside biosafety bags. Goldberg then spent the afternoon performing a series of molecular tests on the tissue samples. He found no sign of hepatocystis.

He spent the rest of the week conducting more tests, checking whether something might be interfering with the chemistry and skewing his results. Still negative.

In his black lab notebook, he noted that ahead of him lay "a huge task."

Not that the challenge displeased him. He loved a good mystery.

Goldberg and David O'Connor, a colleague at UW's Primate Center, compared Mahal's genetic sequence with that of another orangutan, obtained from a massive DNA repository known as GenBank.

The scientists took Mahal's sequence, then subtracted the other orangutan's. What remained, Goldberg reasoned, would contain the killer's genetic signature.

They performed the analysis using a technique known as shotgun sequencing. Long strands of DNA are broken into millions of smaller,

easier-to-read pieces and then reassembled by computer into the longer sequence. They felt compelled to work quickly.

"We really rushed it," Goldberg recalls. "We were really curious and we were afraid there would be an outbreak at the zoo."

He kept thinking about the story of Tracey McNamara, then head pathologist at the Bronx Zoo. In 1999, McNamara noticed that a disturbing number of crows near the zoo were becoming ill and dying. Around the same time, New York City health officials discovered that a small number of people had become deathly ill with what appeared to be St. Louis encephalitis. Mosquitoes pick up the virus from birds, then pass it to humans.

Tests showed, however, that the virus making the crows and humans sick wasn't St. Louis encephalitis. It was West Nile virus. The virus had been discovered in Uganda in 1937, but the sick crows at the Bronx Zoo marked its first appearance in the U.S.

By the time Goldberg began working on the Mahal case, West Nile had spread across the continental U.S., sickening almost 2,500 people and causing 119 deaths in 2013 alone. Early on in his investigation of the orangutan's death, he had no way to know whether he might be dealing with another West Nile virus.

A few weeks of genetic testing provided Goldberg with an answer - of sorts.

The killer's DNA appeared to be that of a cestode, or tapeworm.

Except the sequence didn't match any known tapeworm.

It was something new.

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A tapeworm would not have topped the list of likely suspects. Although orangutans experience roundworm infections, it is much rarer to find one suffering from tapeworms.

In Mahal's case, the tapeworms were still in the larval stage; that explained the little gray bubbles. A tapeworm's life cycle begins when eggs are excreted in the feces of a host animal, let's say a cat, and wind up in the soil. There, they are ingested by a different animal, a secondary host, such as a mouse. The eggs hatch inside the mouse and wait to be ingested back into the cat, where they reach adulthood and reproduce, so that new generations of eggs can be excreted back into the soil.

Mahal appeared to have played the role of "accidental mouse." But what species of tapeworm did the larvae come from? How did they get inside an orangutan? And how did they survive the anti-worming medication the Milwaukee zoo administers to its orangutans every three weeks?

The puzzle of Mahal's death had hooked Goldberg.

"This is the thing you dream about," he says. "An unusual infection caused by something unknown."

Although researchers discover new tapeworm species on a regular basis, Goldberg was dying to run into the offices of his UW colleagues exclaiming: "Look what I found!"

Science, however, demands the opposite response: silence and self-discipline. First come weeks or months of rigorous confirmation work. Only then is a discovery announced.

"There's this delicious little time," Goldberg says, "when you have it all

to yourself."

One answer did emerge rather quickly, though it would ultimately raise new questions.

On the very day Goldberg received the sequencing information from the machine, a scientific paper appeared in The International Journal for Parasitology naming a new genus, or group, of tapeworms. Scientists discovered the new group inside the bodies of weasels in Japan and Finland.

Features that distinguished the new tapeworm from the two previously known groups included a retractable conelike structure armed with hooks used to attach itself to the host's intestinal wall; a small head, or scolex; and suckers. Because the tapeworms found in Mahal were only larval, they displayed none of these features.

Rather, what linked the new group, Versteria, to the larvae inside Mahal was a similar genetic signature. Although the two were not an exact match, they appeared to be different species within the same group.

And from what Goldberg could tell, the tapeworms inside Mahal were a long way from home.

For one thing, they should not have been inside the body of an orangutan, but rather a vole or some other variety of weasel prey. For another, they had been found previously in Finland and Japan, half a world away from Wisconsin.

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Where and how Mahal ingested the tapeworm larvae remained a mystery. Still, Goldberg felt a need to write up what he knew so far.

"You want to publish because it could be important," he says. "You want to get it out there and raise the alarm.

"This could be a threat to orangutans and other apes - such as people."

There was another reason to publish soon. Khan and the rest of the staff at the Milwaukee County Zoo remained in mourning for Mahal.

"We needed answers," Khan says, "as does anyone suffering a big loss."

They needed to know whether what had killed Mahal might pose a threat to the orangutan's surrogate mother, MJ, or to any of the zoo's other primates. Another question was harder and more personal: Could they have done something to have saved Mahal?

From what he knew already, Goldberg was convinced the orangutan's death did not result from anything the zoo staff had done or failed to do.

In January 2014, Goldberg and co-authors at UW and at the Milwaukee County Zoo, published what they knew in the journal Emerging Infectious Diseases, put out by the U.S. Centers for Disease Control and Prevention. Mahal had died from infection by a new species of tapeworm.

So far, the tapeworms did not appear to have infected any other animal at either the Milwaukee zoo or at the zoo in Colorado where Mahal lived previously.

Yet the authors concluded Mahal's "rapid and severe disease progression raises concerns about the health of captive apes in similar settings. Moreover, the close evolutionary relationship between orangutans and humans raises concerns about the parasite's zoonotic potential."

In other words, scientists could not rule out the possibility that what had killed Mahal could also harm a human.

Goldberg knew his investigation was far from finished.

One day in the midst of his work, he sat on a bench outside Mahal's enclosure at the Milwaukee zoo, contemplating how much he did not know.

"I was trying to imagine myself as a tapeworm," he says, "and I kept wondering: How did a tapeworm known only in (Finland and Japan) wind up in Milwaukee? I was looking around at nature and trying to piece together the whole story."

The story's next installment would take Goldberg another two years to nail down.

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He had an idea how the tapeworm larvae had wound up inside Mahal.

Some orangutans like to eat dirt. Coincidentally, tapeworm eggs spend part of their life cycle in the soil waiting to become dinner for a passing vole or mouse. Perhaps Mahal had been eating dirt and accidentally ingested a mouthful of tapeworm eggs.

Once inside Mahal, the eggs would have developed into the gray, larval cysts that Goldberg and Gendron had observed. These thick walls of tissue could have shielded them from the zoo's regular deworming treatment. It is also possible that the treatment simply wasn't effective in killing this type of larvae.

The theory still left open the question of how Mahal had picked up a

genus of tapeworm previously found only in Finland and Japan. The orangutan had never been to those countries. The only homes he'd known were the zoos in Colorado Springs and Milwaukee.

Using a grant from the American Association of Zoo Veterinarians, Goldberg continued his investigation. The trail now retraced a crucial part of Wisconsin's history, its early settlement in the mid-1600s by French trappers hoping to expand the fur trade (one reason the state has so many communities with French names - Prairie du Chien, Eau Claire, Fond du Lac and so on).

Odd as it might seem, the wildlife the French sought more than three centuries ago now held answers to the death of an orangutan.

Enlisting help from the Wisconsin Trappers Association, Goldberg set wildlife traps baited with fish and peanut butter around the zoo grounds. Captured animals were kept only long enough to get feces, which were then checked for tapeworm eggs.

Although a variety of wildlife passes through the zoo grounds, the traps only succeeded in capturing raccoons. A weasel had been spotted in a nearby monkey enclosure, acquiring the nickname "The Weasel of Monkey Island." So Goldberg set special weasel traps, which are long and skinny and baited with sardines.

But try as he might, he never captured the elusive weasel.

More significantly, he never found Mahal's species of tapeworm anywhere on the grounds of the Milwaukee zoo.

"That was the first clue we were on to something much bigger," he says.

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How much bigger?

Think beyond biology. Think astronomy.

The scientists who had identified the new genus of tapeworm Versteria, a close relation of the one that killed Mahal, had made their discovery while working on something called the Beringian Coevolution Project.

The study focuses on species that migrated from Europe and Asia to North America during the last glacial period, which began about 110,000 years ago and ended 11,700 years ago. These periods, marked by colder temperatures and advancing glaciers, occur within the much longer epochs known as ice ages.

Periods of ice followed by periods of relative warmth are driven in part by gradual changes in the earth's axis and another set of overlapping changes in the planet's orbit around the sun. Our orbit is not a perfect circle, but more of an egg shape, or ellipse. Taken together, the pattern of changes that results in these periods of ice is known as a Milankovitch cycle after its discoverer, the Serbian mathematician Milutin Milankovitch.

This phenomenon brought on the last glacial period, which, in turn, resulted in the creation of a land bridge connecting Siberia and Alaska. The land bridge allowed new species of animals to cross into North America carrying with them hardy stowaways: their parasites.

The migration thousands of years ago may have brought a new kind of tapeworm to North America and set in motion the events that led to Mahal's death.

This sense of history - the echoes from the last glacial period, and from the fur-trapping history of Wisconsin - only deepened Goldberg's

fascination.

The strange death of a single zoo animal had taken him into the past. What he found might offer a glimpse of our present, or at least the not-so-distant future, a time when diseases and parasites on other continents no longer appear as far-off threats. They travel, as we do, by planes, bullet trains and automobiles.

"This is the clinical case," Goldberg says, "that ties everything together."

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About 10 months after the tapeworm paper was published, Goldberg came to Colorado State University to give a talk on the Mahal investigation. Afterward, he was approached by a veterinary student named Margot Stuchin.

Stuchin had been performing animal dissections and was scheduled to work on a group of deceased ermines, weasel-like creatures. She asked if Goldberg would be interested in any tapeworms she happened to find.

Like so many aspects of the investigation, this chance meeting would convince Goldberg that a sense of fate hovered over the project.

In the coming months, Goldberg went through the guts of a mink, five long-tailed weasels and 11 ermines. Inside an ermine trapped about 30 miles from the Milwaukee County zoo, he found a tapeworm that looked suspiciously like Versteria.

The student in Colorado also found tapeworms that resembled Versteria in an ermine.

To make matters yet more complex, a group of researchers in Oregon

found tapeworms in a mink that also appeared similar.

It remained unclear whether Mahal had ingested the tapeworm that killed him in Colorado Springs or in Milwaukee. Again, Goldberg turned to DNA for the answer.

When his team scoured the genetic scripts of the tapeworms found in Wisconsin, Colorado and Oregon, they discovered that the tapeworms found only 30 miles from the Milwaukee County Zoo were just 90 percent similar to those found inside the orangutan. While that may sound like a close match, consider that humans and orangutans share about 97 percent of their DNA sequence.

The tapeworms found in Colorado were much closer to those taken from Mahal - 99.5 percent similar. Those found in Oregon also were closer, 99.2 percent similar to Mahal's.

The DNA findings suggest the orangutan likely ingested the tapeworm eggs in Colorado, which would mean that when Mahal arrived in Milwaukee, he already carried the infection that would kill him.

The science of DNA had unmasked Mahal's killer and pointed to its origin. But the tapeworm took some secrets to its grave.

For one thing, zoo staffs in both Colorado Springs and Milwaukee do not remember ever seeing Mahal eat dirt. Nor do written records in Colorado mention the behavior.

And then there is this question: If Mahal had come to Milwaukee with the tapeworm larvae already inside him, why had the infection waited four years before multiplying explosively through his body and killing him?

"My gut tells me," Goldberg says, "we will never know for sure."

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A second paper by Goldberg and colleagues appeared in the Emerging Infectious Diseases journal 3 { years after Mahal's death, explaining the origin of the tapeworm larvae.

At the Milwaukee County Zoo, Khan remained in mourning.

"Mahal was a once-in-a-lifetime animal," she says. "I miss him every day."

Although some questions remained, Khan was grateful to Goldberg for his work.

"A lot of it has been answered," she says. "It's put a lot of our minds at ease. There's nothing we could have given him that would have treated him or stopped his condition."

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On the surface, the story of Mahal's death might seem reassuring in its implications for human health. After all, no humans were sickened by the species of tapeworm that killed Mahal. The tapeworm did not even spread to other animals in the Milwaukee County Zoo.

That could have been good luck.

Other evidence has emerged suggesting that humans and tapeworms may be on a collision course in ways we don't fully understand.

Late in his work on the Mahal investigation, Goldberg came across a

2015 paper in the New England Journal of Medicine that discussed the bizarre case of a 41-year-old man from Medellin, Colombia. The man had been infected with the HIV virus, but in January 2013 doctors found unusual cells in his body.

"The doctors in Colombia were in a dilemma. The cells were small like a nonhuman organism, but they were growing like cancer, like human cancer. It was a complete mystery," explains Atis Muehlenbachs, one of the authors of the paper and a staff pathologist in infectious diseases at the CDC.

The Colombian doctors consulted Muehlenbachs and his colleagues. When the CDC team examined the DNA of the strange, tumorlike cells, they turned out to be nonhuman. They came from a species of tapeworm called Hymenolepis nana, better known as the dwarf tapeworm.

The CDC researchers investigated the cells' odd resemblance to cancer and were led to a stunning conclusion. The tapeworm cells were indeed cancerous and had caused the unfortunate Colombian man to develop large masses in his neck and lungs that contributed to his weakness and fatigue.

For the first time in medical history, scientists had found that cancerous cells in a parasite could spread to a human host. In other words, a parasite could give a human cancer.

In June 2013, just 72 hours after the CDC reached its diagnosis, the Colombian man died. Muehlenbachs says that while the man's HIV infection was his primary illness, the tapeworm cancer contributed to his death.

Goldberg contacted the CDC about the Colombian case. And he has wondered if some kind of tapeworm cancer may also explain why Mahal

got so sick so suddenly after living with the parasite possibly for years without apparent illness.

Another thought gnaws at Goldberg, a worry of a more traditional sort.

During his research at the Milwaukee County Zoo, the scientist walked around the enclosures looking for signs of contact between zoo animals and local wildlife. As he did so, he encountered one example of how an animal's parasite might come to invade a human host.

"I was watching young kids drop their cotton candy on the ground and pick it up and continue to eat it," he says.

Had Mahal ingested the tapeworm eggs in Milwaukee, not Colorado Springs, there's a good chance more eggs would have remained scattered across the zoo grounds, anywhere they happened to have been excreted by their weasel host.

There, in the soil, the parasite eggs would have waited to enter the next host.

Animal or human.

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HOW WE REPORTED THIS STORY

This story is based on extensive interviews with staff at the Milwaukee County Zoo, researchers who investigated the death of the orangutan Mahal, and dozens of experts in glacial periods, parasites, primates and zoonotic diseases. The Milwaukee Journal Sentinel also interviewed Tracey McNamara, former head pathologist at the Bronx Zoo, who helped discover the appearance of West Nile Virus in New York in

1999, and consulted one of the Finnish scientists who discovered the tapeworm genus Versteria. The story also made use of more than a dozen published reports and scientific papers. A few places mention what a source thought or wondered; in such cases, the source explained their thinking during interviews.

Milwaukee Journal Sentinel reporter Mark Johnson is studying the growing threat posed by diseases that jump from animals to humans during a nine-month O'Brien Fellowship in Public Service Journalism at Marquette University.

He is being assisted by Marquette student researchers McKenna Oxenden, Ryan Patterson and Devi Shastri.

Marquette University and administrators of the program played no role in the reporting, editing or presentation of this project.

Additionally, the Pulitzer Center on Crisis Reporting, which funds overseas reporting on underreported topics, is providing support for this ongoing series of stories.