NEWS

The Dynamic Gut

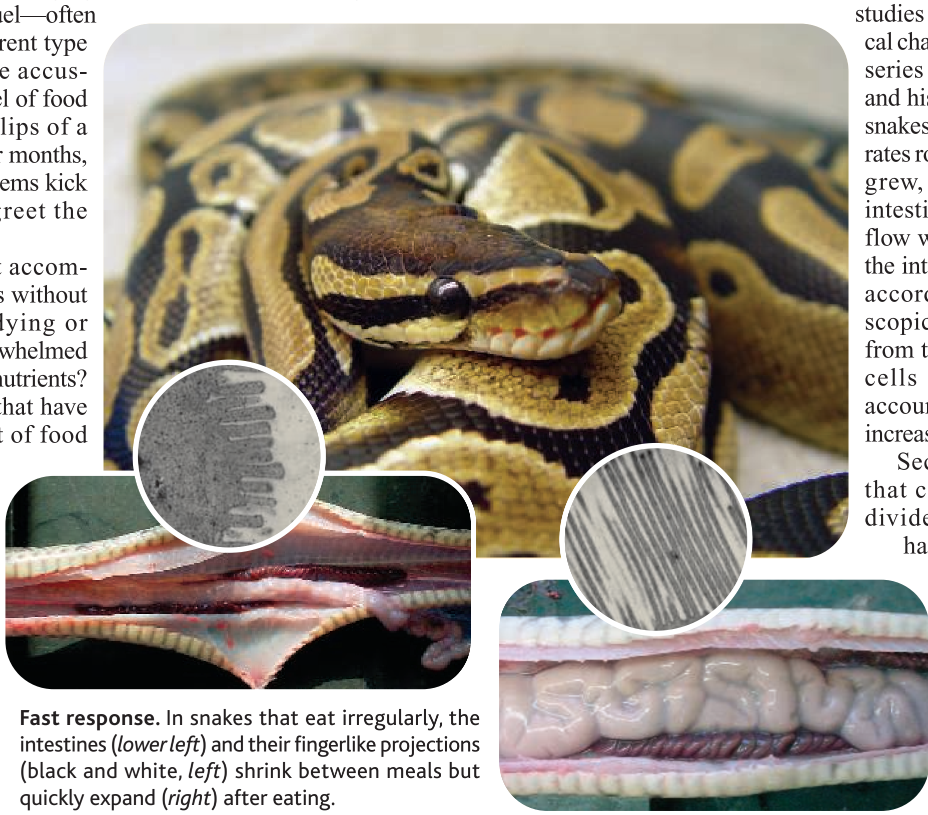
As snakes, frogs, birds, and other wild creatures attest, digestive systems need flexibility to meet energy demands as well as the challenges of environment, diet, and predators

You haven't had a meal for so long that your stomach and intestines have atrophied. And when you finally do get something to eat, it's almost as big as you are. Yet you cram it into your mouth and hope that your gut can somehow cope with it. That's what life's like for many snakes: feast or famine.

Other animals ride similar nutritional roller coasters. Birds travel thousands of kilometers without eating, then gorge themselves when they stop to refuel—often on a completely different type of food than they are accustomed to. Not a morsel of food or liquid passes the lips of a hibernating animal for months, yet their digestive systems kick in as soon as they greet the world again.

How does the gut accommodate such extremes without shriveling up and dying or being completely overwhelmed by a sudden flood of nutrients? Those are questions that have given biologists a lot of food for thought.

"Most of us learned in our textbooks about a rather static digestive system," says William Karasov, a physiological ecologist at the University of Wisconsin, Madison. But "the gut is a very dynamic organ." It can "adjust to changing demands and energy supply," adds Matthias Starck, a functional morphologist at the University of Munich, Germany. And those adjustments can be radical in the extreme.



Fast response. In snakes that eat irregularly, the intestines (*lower left*) and their fingerlike projections (black and white, *left*) shrink between meals but quickly expand (*right*) after eating.

CREDITS (TOP AND MIDDLE RIGHT): MATTHIAS STARCK; (MIDDLE LEFT AND BOTTOM LEFT AND RIGHT) STEPHEN SECOR

The guts of a python's survival

Among those intrigued by the gustatory habits of snakes are Jared Diamond, a physiologist at the University of California, Los Angeles, and Stephen Secor, a physiologist now at the University of Alabama, Tuscaloosa. In 1995, they reported that during the months between meals, the python's stomach and intestine atrophy. Yet once the snake begins to eat, it quickly revs up its digestive function. Secor and Diamond's work suggested that the first food to reach the gut—particularly proteins or their amino acids—stimulates a dramatic expansion of the gut lining. The intestine doubles in size, significantly increasing its absorptive surface area.

Over the past decade, Secor, Starck, and, more recently, Jean Hervé Lignot of the Louis Pasteur University/CEPE-CNRS in Strasbourg, France, have worked independently and collaboratively to sort out how this gastrointestinal rebirth occurs with every meal. The gut lining consists of "fingers" of cells called villi, and the cells themselves sport projections called microvilli. Secor's initial research indicated that new cells are added to the gut lining when the intestine shifts into high gear. That shift, especially the rapid reactivation of the stomach and the production of stomach acids, is quite energy-intensive, taxing the body's reserves, he says.

Over the past 5 years, Starck has developed an alternative explanation, one he will detail in an upcoming issue of the *Journal of Experimental Biology*. He finds that the gut lining grows not because the number of cells increases but because blood pours into shrunken villi once a snake eats, expanding the surface area of the villi and flooding them with materials needed to digest the incoming meal. According to Starck, this proposed mechanism requires less energy than Secor's original explanation; digestion can begin even when fat reserves are relatively low, he notes. And once digestion starts, the ingested food provides the energy needed to complete it.

Starck's new proposal draws on ultrasound measurements of blood flow to and within the gut lining, as well as histological studies that characterize physical changes in the lining. In one series of experiments, Starck and his colleagues fed mice to snakes. The snakes' metabolic rates rose, their small intestines grew, and blood flow to the intestines tripled. This blood flow was responsible for half the intestine's increase in size, according to Starck. Microscopic globs of fat absorbed from the gut further bloat the cells lining the intestine, accounting for the rest of the increase, he says.

Secor too has now found that cells swell rather than divide, but he thinks blood has little to do with their expansion. Instead, his work indicates that the lining's villi absorb the digestive fluids from the gut itself. Working with Secor, Lignot has used electron microscopy to show that each cell's microvilli also swell significantly, quadrupling in size within 24 hours.

Even though Secor maintains that increased blood flow is not the secret to the rapid growth of a snake gut, he has shown that it is important to digestion. Animals typically divert blood to the gut during digestion, just as exercise results in increased circulation to muscles. Last year, Secor and his colleagues reported that snakes go to extremes, increasing blood flow to the gut by about 10-fold compared to the 50% increase humans experience during digestion. "[It's] really going through the roof," Secor notes. "The cardiac output is comparable to somebody going full-

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