New detoxification pathway for mercury in penguins

An international team of scientists led by the ESRF, the European Synchrotron, Grenoble, France, has found that emperor penguins detoxify mercury with both sulfur and selenium, a new pathway for a marine predator. This new detoxification pathway for mercury has been unveiled in a study published in the Journal of Hazardous Materials.

Mercury is considered by WHO as one of the top ten chemicals of major public health concern. Mercury bioaccumulates in organisms along time and biomagnifies in aquatic and terrestrial food webs as the neurotoxic form of methylmercury. Understanding the internal detoxification processes of methylmercury in animals is essential for protecting wildlife and designing treatments against mercury poisoning.

Alain Manceau, ESRF scientist and researcher emeritus at the CNRS, together with his collaborators from the University of La Rochelle and the CNRS (LIENSs and CEBC), the United States Geological Survey, and the University of California Davis, has been studying how animals detoxify mercury for years. Back in 2021, they unveiled that apex predators, such as seabirds like giant petrels, and marine mammals like pilot whales, detoxify methylmercury through a sequence of reactions involving reduced selenium in the form of a prominent selenoprotein. Since mercury is ultimately detoxified as nontoxic mercury selenide, it has diminished toxicological consequences as long as there is sufficient selenium, because mercury selenide is chemically inert.

"*We knew the mechanism that animals that are exposed to large quantities of mercury use; now we wanted to find out what happens with animals that are lower in the food chain, such as penguins*", Manceau explains. Emperor penguins feed mostly on Antarctic silver fish and squid, which contain methylmercury, albeit not in large quantities. Because of this, penguins are less contaminated with mercury than toothed whales, giant petrels, and other predators higher in the food web.

Unknown detoxification pathway in animals

The scientists, who used X-ray absorption spectroscopy, identified, for the first time, a second demethylation pathway of toxic methylmercury. In Emperor penguins, the toxic mercury is partially detoxified using the same chemical pathway as giant petrels, but theses penguins have also developed a second mechanism whereby their body forms a Hg-dithiolate complex. This complex binds to cysteine amino acids in enzymes, altering their function. This demethylation pathway had never been observed before in animals, only in bacteria.

To get to these results, Manceau and Pieter Glatzel, ESRF scientists, used a synchrotron technique called high energy-resolution X-ray absorption near edge structure spectroscopy (HERFD-XANES) to study the form of mercury in the liver of Emperor penguins. They then paired their data with nitrogen and mercury stable isotopes to identify the dietary source of methylmercury and the chemical reaction pathway. The isotopic composition of the Hg-dithiolate complex showed that demethylation takes place inside the body, and not in the gut microbiome.

"*We believe that this 'less elaborated' demethylation pathway is more common in lower-trophic level vertebrates as they are less contaminated with methylmercury and do not need an advanced system like giant petrels*", explain the authors. The next step is to analyze snakes, crocodiles and Bluefin tuna, a top predator fish.

The research is important because it fills knowledge gaps in the biogeochemical cycling of mercury across aquatic and terrestrial ecosystems, from bacteria to top predators.

Mercury transfer from mother to chicks

Thanks to an expedition to Antarctica, scientists also obtained penguin eggs for analysis that had been abandoned by the parents in early incubation, which takes place in the cold and dark winter.

Until now, it was known that penguin mums transfer methylmercury in the albumen (egg white) of the egg to their chicks. In the same study, it was discovered that, in the yolk of the egg, part of the mercury is detoxified thanks to the advanced pathway, which penguins partially use. However, the majority of mercury in the egg is present as the toxic methylmercury form, due to the disproportionate amount of albumen compared to the yolk.

"*Still, elimination of toxic mercury during egg production is quantitatively minor compared to depuration into feathers during molting*", concludes Paco Bustamante, Professor at the University of La Rochelle. It is a bit like in humans, where methylmercury is partly eliminated through the hair, while its placental transfer during mother's pregnancy is known to impact the fetus' neurodevelopment.

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