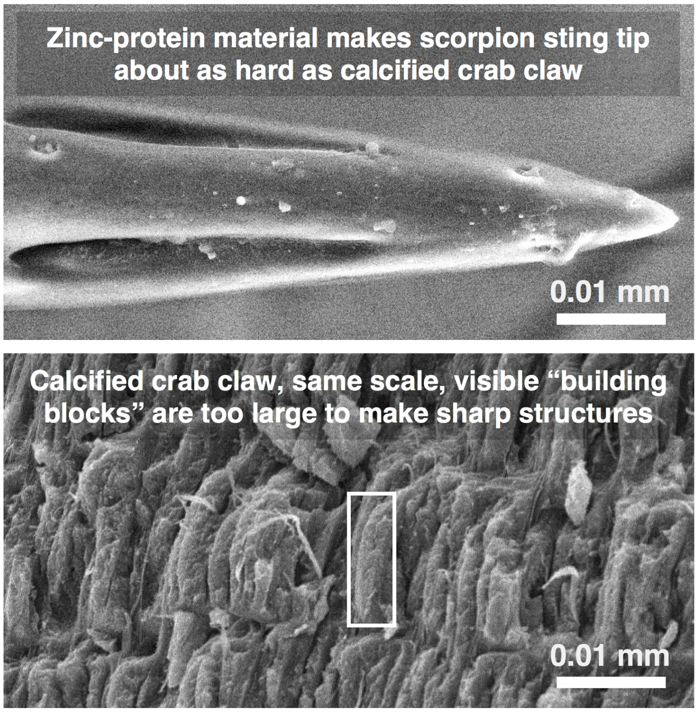
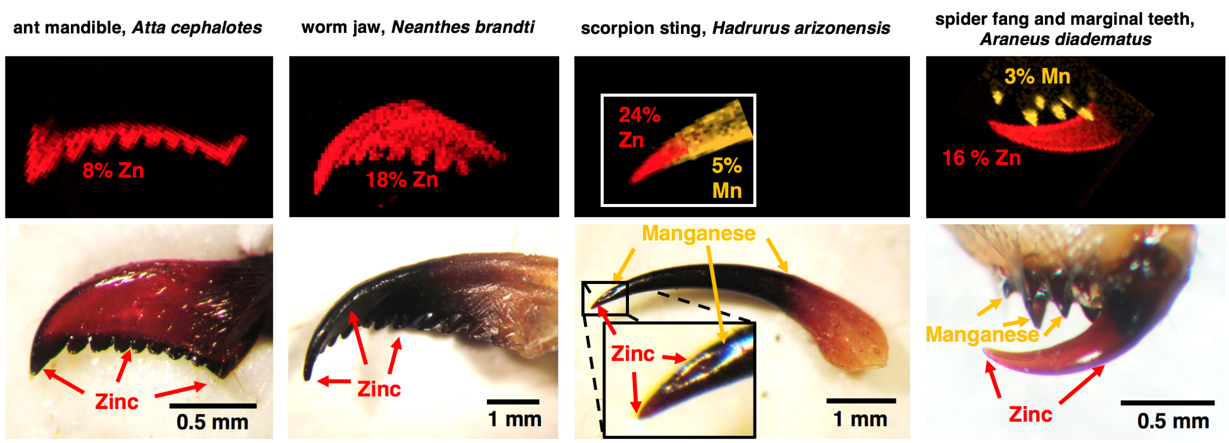


Scanning Electron Microscope images compare a zinc-HEB scorpion sting (top) and, on the same scale, a calcified crab claw (bottom). It would not be possible to make the sharp zinc-HEB tool out of building blocks as large as the mineral chunks in the crab claw.

Outreach video showing tools of ants, worms, scorpions and spiders in action: https://vimeo.com/531534040/55c49aad11



Biomaterials that incorporate zinc (red) and manganese (orange) are located in the important cutting and piercing edges of ant mandibles, worm jaws and other tools. The top row images were made using a proton microprobe.

Unique materials help insects with tiny muscles puncture tough skin

You may have wondered how spiders, scorpions, ants and other small organisms can so easily puncture your skin, while you would have a hard time biting through the same skin, even with your vastly stronger muscles. The answer is that they focus their tiny forces using very sharp fangs, stings and mandibles. But growing sharp puncturing tools that stay sharp is tricky. Unique materials have evolved that can make scalpel-sharp, damage resistant tools, materials that are full of individually bound zinc or manganese atoms, so many metal atoms that they can make up more than 20% of the total weight of the material.

We studied the materials in the teeth, claws and other "tools" of ants, scorpions, spiders and other small organisms by developing miniaturized testing machines and techniques that can measure mechanical properties of ant teeth and other tiny samples, and we used atom probe tomography to disassemble the materials almost atom-by-atom to study their composition. We found that, if these small organisms made their tools of the same organic material as other stiff parts of their exoskeletons, the sharp edges would deform more, they would not be as hard, and they would often wear away much faster. On the other hand, if they used the calcified material that human teeth are made of, their tools would be hard enough, but they wouldn't be sharp enough because of the large mineral chunks. The solution, we think, was the evolution of materials that are based on proteins, taking advantage of the pre-existing control of shape for protein-based structures in order to form sharp tips and precise edges. The properties of the protein structure are then changed by filling the space in between the proteins with large quantities of individual atoms of zinc and other heavy elements. We suggest that these materials, that we call Heavy Element Biomaterials (HEBs), represent a third class of structural biomaterials, after plain-organic (like claws and fingernails), and biomineralized materials (like teeth and bones).

Human engineers might learn from this biological trick. The hardness of ant teeth, for example, increases from about the hardness of plastic to the hardness of aluminum when the zinc is added. While there are much harder engineering materials, they are often more brittle or ductile.

The advantages of using these materials are significant. We estimated that by allowing for sharper, damage-resistant tools, heavy element biomaterials made it possible for the organisms we studied to use 60%, 20% or even less of the force that they would have to use if their tools were made of plain organic or biomineralized materials. Because less force is required, they can have smaller muscles and spend less energy to obtain food. The large savings are probably strong adaptive advantages from an evolutionary perspective, for example, the energy savings may mean that more energy can be spent producing offspring. These advantages may explain the widespread use of these materials – every spider, ant, many other insects, worms, crustaceans and many other groups of organisms use them.