Prof. Christine Ortiz's work may help engineers create the body armor of the future. Photo: Richard Howard

To Christine Ortiz, the dinosaur eel's tough, mineralized scales are a throwback to the past that may help engineers create the body armor of the future.

*Polypterus senegalus* can still be found in African lakes and estuaries sporting the same full-body armor that's been protecting it from its aggressive cohorts for 96 million years. A single one of these silver-gray fellows can also be found in a 25-gallon tank in the Building 12 basement laboratory of Christine Ortiz, associate professor of materials science and engineering. Nearby, northern Pacific mollusks more than a foot long called *gumboot chitons* curl into invulnerable balls with eight armored plates down their backs. Another tank houses transparent shrimp and spiky sea urchins.

These are only a few of the creatures that inspire Ortiz to explore just how nature managed to create such impenetrable defense systems. The U.S. Army also wants to know. Ortiz's work may lead to innovative, biologically inspired systems to protect soldiers from shrapnel and explosions. It also could launch new materials to protect police officers from bullets and firefighters from heat and toxic chemicals; and to serve as new structural components for buildings, aircraft, vehicles, windshields, goggles, and more.
Ortiz is able to quantify the mechanical properties of many biological exoskeletons for the first time with an arsenal of cutting-edge techniques that nail down mechanical phenomena at a scale so minuscule it’s hard to imagine. Previously, such materials were too small and irregularly shaped to be able to experiment on them. Working at the nanoscale, Ortiz believes her approach to fathoming the secrets of natural armor and musculoskeletal tissue is unique.

SKELETON CREW

When she joined the MIT faculty in 1999, Ortiz began studying the nanomechanics of musculoskeletal tissues in collaboration with Professor Alan J. Grodzinsky of the MIT Department of Biological Engineering with the intent of understanding the function and pathology of cartilage, bone, and other connective tissues. “Nanotechnological methods applied to biological materials such as cartilage and bone hold great promise for significant and rapid advancements toward tissue repair and replacement, improved treatments and possibly even a cure for people afflicted with diseases such as osteoarthritis,” Ortiz says. “The hope of discerning the molecular origins of disease, aging, and regeneration has motivated my research in this area for the past several years. Biological materials are so complex and so efficient,” she says. “I’ve always gravitated toward exploring them.”

Ortiz then expanded her scope from musculoskeletal to exoskeletal tissues or “natural armor.” “We house live animals in the laboratory that possess unique exoskeletons and observe how they move and behave,” she says.

There exists a diversity of exoskeletons in nature, such as flexible articulating armor, some that resist biochemical toxins; some that are beneficial for penetrating attacks, fatigue, or projectiles; and some that have to regulate enormous thermal fluctuations. In addition to armored fish, mollusks, and echinoderms with articulating plate armor, Ortiz’s model systems include deep sea hydrothermal vent mollusks, crustaceans, and sea snails with transparent exoskeletons, and insects such as the Bombardier beetle, armed with two miniature internal cannons that set off real explosions of acrid vapor to ward off its ant enemies. The beetle’s ability to withstand internal explosions could help engineers design materials enabling humans to survive external ones.

“Sporting equipment, protective clothing — I can think of so many potential applications,” Ortiz says. Her goal is to develop a library of nature-inspired designs that can be applied to a host of medical and engineering applications.

POINT OF ATTACK

Each of the dinosaur eel’s armored scales is made up of four separate materials in layers around 100 millionths of a meter thick (a human hair is 50 millionths of a meter). Ortiz’s research team analyzes a single scale to determine how its layers’ geometry, thickness, sequence, and separation add up to a design that helps the fish survive a penetrating attack.

Mimicking a bite on a scale that had been surgically removed from the anesthetized fish, the team found that the P. senegalus armor kept the crack localized at the point of attack rather than spreading, which could lead to the scale’s catastrophic failure. It is, Ortiz says, a pretty amazing design.

“The Stickleback is another example of an armored fish. When populations come from different locations (freshwater lakes versus marine for instance) they have different types of armor depending on their local predators and environment.

“Many of the questions being asked in evolutionary biology and in engineering are the same: How is armor designed to resist specific threats in specific environments?” Ortiz says. “The information we provide can be used to answer questions in both fields.”

by Deborah Halber