On quills and needles: Prickly porcupine is a muse for future medical devices

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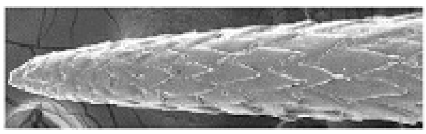

This is a microscopic view of a synthetic porcupine quill. Credit: Karp Lab

Researchers from Brigham and Women's Hospital (BWH) have uncovered how North American porcupine quills easily penetrate tissues and why, once lodged in flesh, they are often difficult to remove.

The researchers, led by Jeffrey Karp, PhD, BWH Division of Biomedical Engineering, Department of Medicine, senior study author, along with Robert Langer, Ph.D from Massachusetts Institute of Technology (MIT), state that the discovery could prompt device makers to design medical needles that easily penetrate surfaces and resist buckling, as well as create next-generation medical adhesives.

The study will be published online on December 10, 2012 in Proceedings of the National Academy of Sciences.

The scientists used natural porcupine quills and replica-molded synthetic polyurethane quills to understand the physical forces at play when the quills penetrate and are removed from a variety of tissues, including muscle and skin.

The North American porcupine has approximately 30,000 defensive quills on its back. The porcupine releases its quills upon contact with predators. Each quill contains a conical black tip studded with a layer of microscopic, backward-facing barbs and a cylindrical base with smooth, scale-like structures.

The researchers revealed that the quill's geometry enables it to penetrate tissue with ease, and once in the tissue it maintains high adhesion.

"The philosopher Aristotle who was clearly misinformed warned that porcupines could shoot their quills over great distances, which is completely untrue," said Karp. "In fact there are many misconceptions about porcupines and their quills. We were most surprised to find that the barbs on quills serve a dual function. Namely, the barbs reduce the penetration force for easy insertion into tissue and maximize the holding force to make the quills incredibly difficult to remove."

According to the researchers, since quills do not shoot through the air, they must penetrate tissue very easily and thus have evolved a specialized mechanism to achieve this that depends on the backwards-facing barbs. The barbs can be thought of as similar to serrated blades that require less work to cut tissue by localizing forces at the tips of the teeth of the blade. Just as serrated blades provide cleaner cuts in tissue, the barbs appear to minimize the penetration force through reducing the deformation of the tissue.

"By carefully removing the barbs' from the quill, we discovered that in addition to their physical features, the location of barbs on the quill played a major role in minimizing penetration forces and maximizing the work needed to yank them from the tissue," said Woo Kyung Cho, PhD, BWH Division of Biomedical Engineering, Department of

Medicine, first study author.

The authors compared the potential of this finding to other things in nature that have inspired bioengineered devices, such as the development of Velcro hook-and-loop fasteners and the development of tape-based adhesives inspired by geckos.

The researchers expect that this approach should have many implications across multiple disciplines including medicine. "This is especially true given that quills can strongly grip tissue with minimal depth of penetration, less than half a centimeter is enough and they don't need to bend like staples to achieve secure fixation," said James Ankrum, PhD, MIT graduate student and study co-author.

"Towards medical applications we developed plastic replicas that remarkably mimicked the reduced penetration force and increased pullout. This should be useful to develop next generation medical adhesives and potentially design needles with reduced pain," added Karp.

According to the researchers, the next step will be to test the synthetic porcupine quill approach in a variety of medical applications.

"This work is a valuable addition to our understanding that bio-inspired materials or devices have great potential to revolutionize the existing biomedical materials and tools from drug delivery to tissue engineering," said Kahp-Yang Suh, PhD, School of Mechanical and Aerospace Engineering, Seoul National University, and an expert in biomechanical innovations.

Provided by Brigham and Women's Hospital