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Are our bones well designed? Insects and crabs have a leg up on us

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Image: Stephen Friedt/Wikipedia.

Researchers from Trinity College Dublin have recently shown that the legs of grasshoppers and crabs have the ideal shape to resist bending and compression. If human leg bones were built the same way, they could be twice as strong.

"Like all Arthropods, grasshoppers and crabs have so called exoskeletons made from a very special material called cuticle," said Professor David Taylor, of the Trinity Centre for Bioengineering at Trinity College Dublin, Ireland. "This exoskeleton protects the animal like a knight's suit of armour. Recently we have shown that this cuticle is in fact one of the toughest natural materials."

"In terms of evolution, having your bones on the outside has been a pretty good concept," said his colleague Dr Jan-Henning Dirks. "Since millions of years animals with exoskeletons such as insects, spiders and crustaceans can be found basically in every ecosystem in the world."

So what makes this exoskeleton so successful? Together the interdisciplinary team used the latest principles of engineering mechanics, materials science and biomechanics to address this question. In particular, Taylor and Dirks were interested in the diameter and thickness of the bones. They used a special computer-tomography machine to generate X-ray images of insect legs with a resolution of only a few thousands of a millimetre and collected and compared data from crabs and human bones.

Their results, published in the article 'Shape Optimisation in Exoskeletons and Endoskeletons: a Biomechanics Analysis' in the *Journal of the Royal Society, Interface*, showed that, whilst human leg bones are relatively thick-walled tubes, the legs of insects and crabs have a much thinner wall in relation to their radius.

"This relation of wall-thickness to radius can tell us a lot about the mechanical stability of the structure," said Taylor. "Imagine the bones as simple tubes. Now, if you had a limited amount of material, what would you do? Would you make a thin solid rod or a hollow, thin walled tube? When compressed, the rod might easily bend like a straw, the hollow tube however might buckle like a beer-can."
However, for a given weight there is a mechanical optimal wall-thickness. And interestingly, the researchers found that the leg-shape of crabs represents an ideal compromise to resist both the bending and compression forces the crab experiences when walking under water.

The locust leg on the other hand is optimised to withstand the huge bending forces which occur when it jumps.

In comparison, the human thighbone didn't do so well. Using the same amount of bone material and taking into account its mechanical properties, the human thighbone could be "redesigned" as an exoskeleton to be twice as strong as it is now.

"Of course there are numerous other factors determining the evolutionary advantages of endo- and exoskeletons," said Taylor. "However, we think that by taking a design engineer's view on the problem we've been able to shed some light on the evolutionary development of skeletal forms."

More information: 'Shape Optimisation in Exoskeletons and Endoskeletons: a Biomechanics Analysis', Taylor and Dirks, in the *Journal of the Royal Society, Interface* (in press)

Provided by Trinity College Dublin