Stag beetles restrain bite force to prevent breaking their own jaws

Males have evolved such strong bite muscles, that they risk breaking their own jaws while pinching. They prevent damage by modulating their bite force with a network of tiny sensors in their jaws. The distribution of these sensors is closely related to the material stress that the jaws have to endure during pinching.

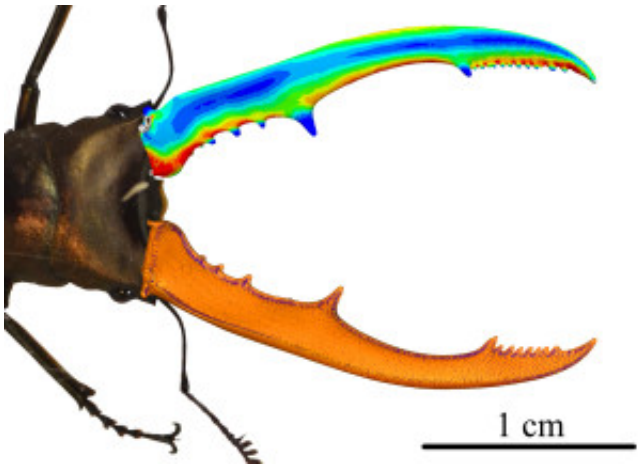

Fig. 1. Male stag beetle head. The colors on the top jaw indicate the material stress in the jaw while biting with the tip of the jaw. Warmer colors indicate higher material stress and a higher risk of breaking the jaw. The Purple dots and lines on the bottom jaw show the location of the deformation sensors in the jaw.

Male stag beetles brawl with each other over females and mating opportunities. They have evolved enormous jaws for this purpose. In some species, the jaws can be as long as the rest of the body. The jaws are used to grab rivals and the winner lifts its opponents high above its own head in the most spectacular battles. Also the bite muscles of the jaws are enlarged in male stag beetles. This enables them to bite 7 times as forceful as females. Being bitten by a male stag beetle feels as if you are balancing two soda cans on tooth picks (one for each jaw) on your finger.

This is such a large increase in bite force, that males even risk to break their jaws if they would bite in full force. Male stag beetles avoid this by carefully restraining their bite force. We measured the bite force of male stag beetles biting in two parallel bite plates, one of which was connected to a force transducer. We compared the muscle force that males exert when biting with the (delicate) jaw tips and with the (robust) teeth halfway the jaws. This revealed that males only use 84% of their maximal muscle force potential when biting with the delicate jaw tips. Computer simulations subsequently showed that, because of this muscle force reduction, the material stress in the jaws

while biting with the delicate tip does not exceed that of bites with the robust teeth. Because a higher material stress indicates that the material is closer to breaking, this indicates that male stag beetles are able to control their bite force precisely to avoid an increased risk of breaking their jaws.

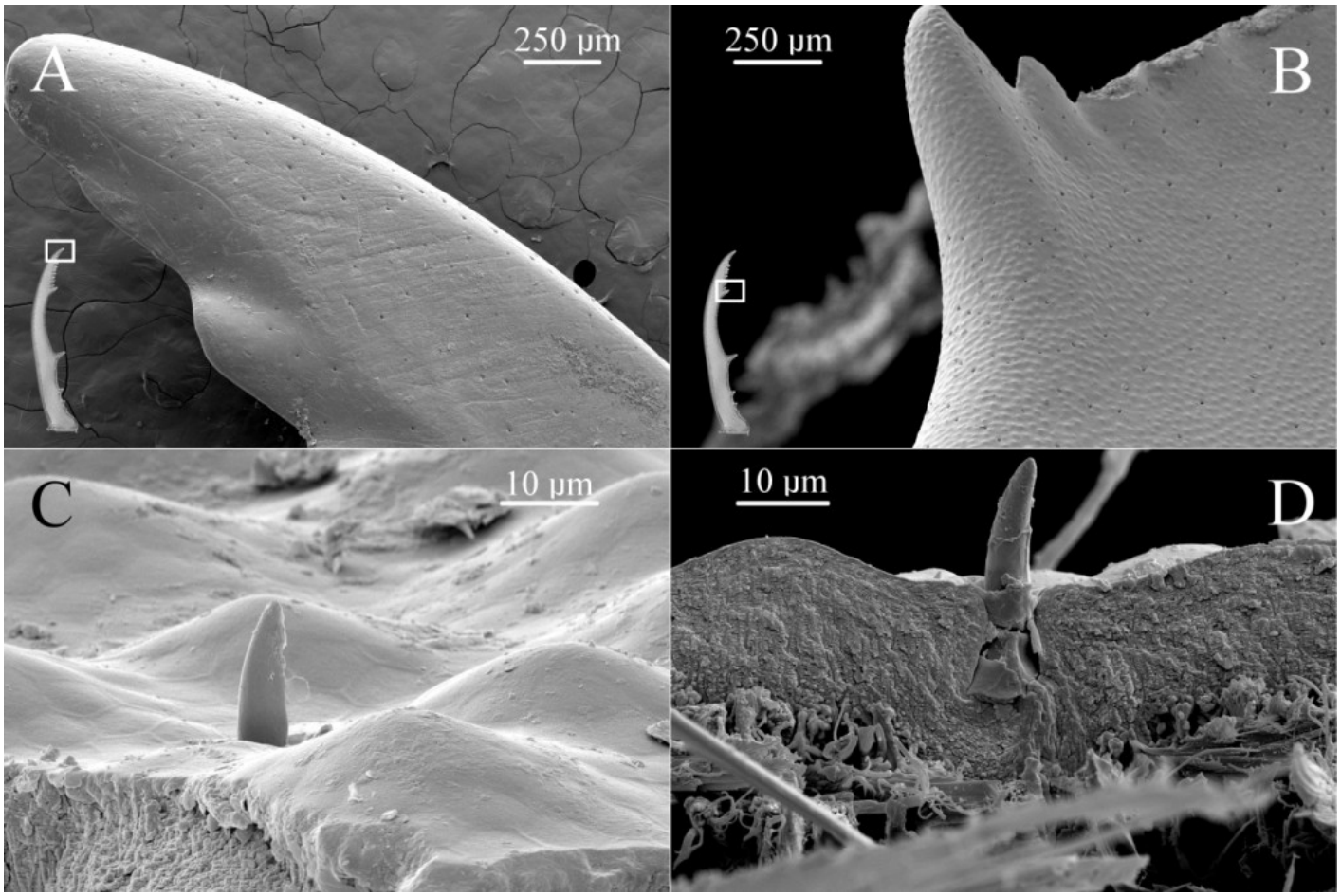

Fig. 2. Scanning Electron Microscopy of the sensors on the stag beetle jaws. A and B show the tip of the jaw. Each dark dot marks the location of a sensor. C and D show a sensor at higher magnification. In D, the sensor is located on a fracture surface through the jaw exoskeleton; fibers of the exoskeleton are visible.

A new question emerged: how can stag beetles control their muscle force so precisely? Under a scanning electron microscope, we saw that the jaws are strewn with tiny sensors. They are about 10 µm long (which is approximately as long as a human hair grows in an hour). They are mechanosensors that sense deformations of the jaws. The sensors have a very peculiar distribution: the density of the sensors is strongly elevated at the edges and tips of the jaws. A comparison with the distribution of the material stress in our computer simulations showed that

both are correlated: jaw regions that suffer from higher material stresses, and therefore a higher risk of breaking, own a higher number of sensors. A higher sensor density implies a more precise registration of jaw deformations. Hence, males possess a network of deformation sensors in their jaws that they use to feel how much bite force they can safely exert on their rivals.

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Publication

Mechanoreceptor distribution in stag beetle jaws corresponds to the material stress in fights.
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