

Inside JEB highlights the key developments in *The Journal of Experimental Biology*. Written by science journalists, the short reports give the inside view of the science in JEB.

Inside JEB

SKATES FINE-TUNE CARTILAGE FOR PUNTING



Undulating their cape-like wings to swim gracefully, skates and rays (batoids) are some of the most enchanting inhabitants of coastal waters. But did you know that many also ‘punt’ along the bottom? Laura Macesic from Mount Holyoke College, USA, explains that some skates and electric rays propel themselves at high speed across the sea floor by pushing against the seabed with their small pelvic fins – it almost looks like running – while others supplement their pelvic fin punting action by pushing with their wings. And they do all this without having a single bone in their bodies: the skeletons of skates and rays are built from cartilage. Intrigued by the mobility range of batoids, Macesic and her colleague Adam Summers decided to find out how a punting lifestyle influences the tiny pelvic fin skeletal structure – the propterygium – that skates and rays use to push off with. They decided to investigate the stiffness and other mechanical properties of propterygia from accomplished punters to non-punters to find out whether the fish’s lifestyle fine-tunes the structure to match (p. 2003).

Joining Summers at his University of California Irvine laboratory, Macesic measured the flexural stiffness of the left and right propterygia from true punters (the lesser electric ray and the clearnose skate), two punters that supplement their punting action by pushing with their wings (the yellow stingray and the Atlantic stingray) and the non-punting pelagic stingray, *Pteroplatytrygon violacea*, which lives in open water. She says, ‘Flexural stiffness is an object’s ability to resist bending when a load is applied. A flexurally stiff object would be better to push off with – you’d get more force transferred.’ Supporting the bone-like skeletal element at two points and pressing down in between with an indenter, Macesic found that the flexural stiffness of the punting rays’ propterygia was the highest (around 126.1 N mm²), with the punting clearnose skate having the highest flexural stiffness for its size. Meanwhile, the propterygia of the supplemented punters had intermediate flexural stiffnesses and the non-punting pelagic stingray had the lowest flexural stiffness (94.9 N mm²).

Curious to find out how the skates and rays achieve such a wide range of flexural stiffness from cartilage-based structures, Macesic began looking at other aspects of the propterygium structure. Taking cross-sections through the propterygia and looking at the distribution of cartilage across the structure, Macesic saw that the clearnose skates oriented the thickest dimension of the elliptical propterygia along the direction of the punt force, protecting it from bending. However, the non-punting pelagic stingrays oriented the thinnest dimension of their propterygia along the punt force direction, reducing the structure’s flexural stiffness, making it useless for propulsion along the seabed.

Next, Macesic analysed the mineral composition of the propterygia and found that the supplemented punters’ propterygia were stiffer than those of the open-ocean species because they had a higher mineral content. However, when she compared the mineral content of the cartilage propterygia with that of bone, it was only a fraction of that of mammalian spongy bone, even though the cartilage was as stiff as some mammalian bones. The team suspects that the tiled structure of the surface of the punter’s propterygia contributes to their remarkable stiffness.

So punting rays and skates have stiffened their propterygia in response to the small forces they experience as they propel themselves across the seabed, and Macesic adds that the open-ocean *P. violacea*, which is poorly equipped for punting, ‘has seemingly lost the adaptation for benthic locomotion.’

10.1242/jeb.074864

Macesic, L. J. and Summers, A. P. (2012). Flexural stiffness and composition of the batoid propterygium as predictors of punting ability. *J. Exp. Biol.* **215**, 2003-2012.

Kathryn Knight

DINOSAUR RANGE OF MOTION STUDIES VINDICATED

Hollywood and the television are obsessed with dinosaurs, and the most charismatic of them all has to be *Tyrannosaurus rex*. With its colossal jaws and powerful build, it terrorised the residents of the upper Cretaceous, despite having remarkably short forelimbs. Joel Hutson from Northern Illinois University, USA, explains that they were barely longer than an adult human’s arms although they appear to have been put to good use grabbing prey. Yet it was not clear how the vicious predators moved the joints in their stunted limbs to grip their victims. So, when Hutson’s thesis advisor, J. Michael Parrish, received casts of the shoulder and forelimb bones from Sue – the

Chicago Field Museum's *T. rex* skeleton – he set about recreating the limb's movements. However, Hutson admits that he was taken aback when he saw how Parrish manoeuvred the bones. 'I thought, "This is unrepeatably"', he recalls, adding, 'I said, "If I do this I have to find a way to make this more scientific"'. Determined to set range of motion studies on a more solid footing, Hutson decided to test how reliable the technique is on two modern – and relatively close – relatives of the *T. rex*: the ostrich and the American alligator (p. 2030).

Obtaining three culled alligators from a reserve in Louisiana and three ostrich wings from local butchers, Hutson and his wife, Kelda, decided first to find out whether they could correctly reassemble the limb bones and measure the elbow's range of motion. Stripping the bones of flesh and arranging them in a horizontal plane, the duo measured the elbow's range of motion with a protractor as they flexed and extended the limb by moving the radius and ulna around the skeletonised elbow joint. Then, having convinced themselves that they could measure the elbow range of motion, the duo embarked on a week-long dissection marathon to find out how the presence of soft tissues affected their measurements.

Painstakingly manipulating the intact limbs in the vertical plane and measuring the full extent of the elbow rotations with an inclinometer while flexing them, the husband and wife team then carefully removed the limbs' skin before repeating the elbow rotations. Systematically dissecting away the muscles and tendons, joint capsules and ligaments, and finally the cartilage, the duo repeatedly measured the elbow's range of motion at each stage, taking it in turns to manipulate the limb to introduce the variation between experimenters that Hutson was sure would make range of motion studies almost unreproducible.

However, when Hutson analysed the elbow rotation angles he was shocked to see that their measurements were reproducible. 'Sometimes our range of motion measurements are up to 70 deg apart, but when you take those hundreds of measurements and average them out, the statistical analysis said there was no difference between experimenters', says Hutson. And when he analysed the impact of the animal's soft tissues on the elbow's mobility, Hutson could see that the bulk of the limb impeded the elbow's rotation, which increased as the duo stripped away the tissue. Hutson says, 'Our summary says that what people do with fossil bones is probably a conservative underestimate of what the range of motion was in the elbow joint in real life.'

Having convinced himself that palaeontological studies of the range of motion of fossil joints are reproducible, Hutson says that he is impressed by the accuracy of previous studies. He adds, 'Those scientists have vast accumulated knowledge in comparative anatomy; they intuitively know where the tendons and muscles were and they knew what they were doing in their range of motion studies.'

10.1242/jeb.074815

Hutson, J. D. and Hutson, K. N. (2012). A test of the validity of range of motion studies of fossil archosaur elbow mobility using repeated-measures analysis and the extant phylogenetic bracket. *J. Exp. Biol.* **215**, 2030-2038.

Kathryn Knight

RAZOR CLAMS TURN SOIL INTO QUICKSAND TO BURROW



Amos G Winter

Amos Winter from the Massachusetts Institute of Technology, USA, wants to build self-burying machines. 'There are many applications that could benefit from a self-burrowing reversible anchor that embeds efficiently as far as energy consumption is concerned', explains Winter. He adds, 'When I started the project our hypothesis was that there is probably an animal that has figured out a pretty good way of digging into soil, so I looked around at animals that dig into the ocean bottom and razor clams stood out.' According to Winter, the 15–20 cm long molluscs can burrow as far as 70 cm down in mud or sand soils beneath the sea, yet muscle force measurements by E. R. Trueman in the 1960s had found that the mollusc's muscles were not strong enough to heave them through that much soil. Intrigued, Winter and his thesis advisor, Anette Hosoi, decided to find out how razor clams burrow (p. 2072).

But first Winter wanted to know how far a clam could force its way through mud at its seashore home propelled by its muscular foot alone. Packing an empty razor clam shell with epoxy resin and pushing it into exposed seashore mud, Winter measured the resistance encountered by the shell and found that the clam could burrow no deeper than 2 cm. They had to be doing something

else to burrow farther, but what? Winter had to get his hands on some animals and successfully reproduce the clam's environment in the laboratory to analyse their burrowing technique.

Having obtained an official permit and after being taught how to collect the molluscs by the Shellfish Constable of Gloucester, Massachusetts, Winter recalls how difficult it was to build a transparent simulation of the mollusc's environment. Hitting on transparent 1 mm diameter soda-lime glass particles as a good substitute for one of the clam's natural homes, coarse sand, Winter filled a narrow chamber with the water-saturated particles and blasted it with two 1 kW halogen bulbs to visualise the clams' descent as they burrowed.

Analysing the clam's burrowing technique, Winter saw that the animal initially extended the foot before lifting the shell up. Then, the clam contracted the shell rapidly, inflating the foot with the blood expelled from its body. Having inflated the foot to anchor itself in place, the clam pulled on the secured appendage to drag the shell further down into the simulated soil. But this still couldn't explain how the clam was able to burrow so far through static soil.

Turning his attention to the glass-particle-simulated sandy soil, Winter eventually discovered that the key to the mollusc's burrowing technique was the moment when it contracted the shell. 'As soon as it starts contracting the shell it relieves the pressure it is exerting on the soil and that sucks more water towards its body so that you get increased unpacking of the soil particles', he explains. Essentially, the clam fluidised the surrounding soil – turning it into quicksand – which dramatically reduced the drag on the shell, allowing the mollusc to pull itself down before the surrounding sand particles slid back into place and the soil resolidified. And when Winter analysed the amount of energy required to move through the temporarily fluidised glass sand, he realised that it was a fraction of the energy required to move through a static soil.

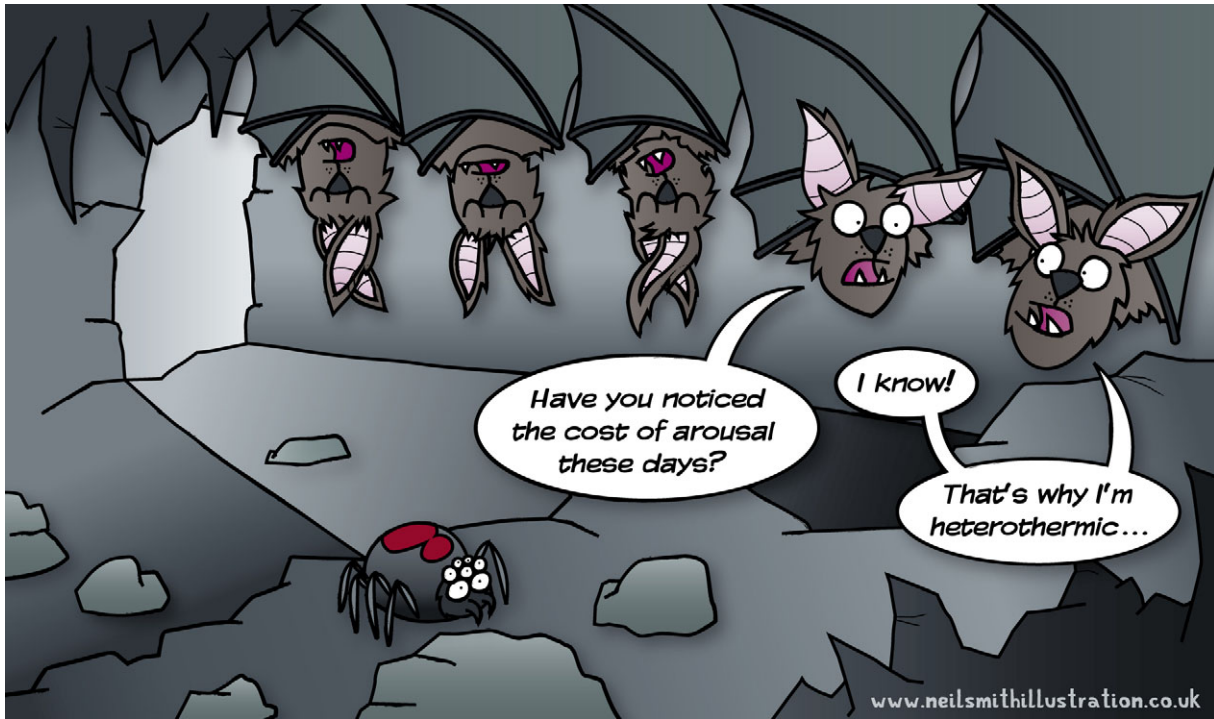
Having discovered how razor clams burrow, Winter has successfully designed and built a machine that burrows using the razor clam's quicksand energy-saving mechanism, which he hopes to develop into a self-contained gadget that can dig into, and out of, the ocean floor.

10.1242/jeb.074807

Winter, A. G., Deits, R. L. H. and Hosoi, A. E. (2012). Localized fluidization burrowing mechanics of *Ensis directus*. *J. Exp. Biol.* **215**, 2072-2080.

Kathryn Knight

BATS USE SHALLOW TORPOR TO MINIMISE COSTS



White-nose syndrome is a devastating fungal disease that is currently decimating the bat populations of North America. Specifically targeting hibernating bats, the disease appears to cause its victims to arouse from torpor more frequently, preventing them from conserving energy and leading to starvation. Craig Willis and Kristin Jonasson from the University of Winnipeg, Canada, explain that it is difficult to assess the energetic impact of this disease without realistic models of how hibernating bats use energy. So, the duo decided to monitor the skin temperatures of hibernating little brown bats to find out whether the hibernating animals optimise their use of torpor during hibernation and how well temperature measurements can be used to estimate the animals' energy consumption rates (p. 2141).

Fitting temperature-sensitive radio transmitters to 22 bats hibernating in a small cave in central Manitoba, Canada, the

duo monitored the bats' body temperatures for 3 months. Recording the lengthy periods when the bats became torpid (13.1 days on average), depressing their body temperatures, and the brief arousals when the animals returned their body temperatures to normal, Willis and Jonasson found that the duration of torpor varied significantly from animal to animal. They also found that the bats were torpid for an impressive 99.6% of the hibernation period.

Next, the pair analysed the temperature recordings to find out whether the bats' age, sex or body condition affected their hibernation. They did not. However, when the scientists analysed the arousal periods, they noticed something unusual. Occasionally the bats dropped their body temperatures slightly during arousal and entered a period of shallow torpor. The duo suspects that the bats use these bouts – which they refer to as heterothermic

arousal – to minimise the over all metabolic costs of hibernation. Finally, the team measured the masses of the tiny animals to estimate their energy use over the course of the hibernation, and found that their calculated predictions of energy use agreed well with the bats' mass loss, although the calculations slightly overestimated the energy consumption.

Having assessed the mammal's hibernation energetics, Willis says, 'Our findings will be important for understanding the energetic and survival implications for bats suffering from white-nose syndrome.'

10.1242/jeb.074823

Jonasson, K. A. and Willis, C. K. R. (2012). Hibernation energetics of free-ranging little brown bats. *J. Exp. Biol.* 215, 2141-2149.

Kathryn Knight
kathryn@biologists.com

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