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INSIDE JEB

Frogs fine-tune springy muscle and tendon for leaps

Cuban tree frog (*Osteopilus septentrionalis*), Grand Cayman, Cayman Islands. Photo credit: Charles J. Sharp, CC BY-SA 4.0, via Wikimedia Commons.

Long before the advent of gunpowder, humans had harnessed the power of catapults in warfare to destructive effect. Yet, biology had already beaten us to capitalising on the power of springs. ‘Fast and powerful movements like the jump of the flea or the strike of a mantis shrimp smasher are possible because they use elastic energy storage mechanisms’, says Elizabeth Mendoza from the University of California, Irvine, USA. Even soft-bodied frogs get in on the action, storing energy in the plantaris longus muscle–tendon unit – linking the back of the knee to the heel – ready for release in powerful leaps. Yet in 2011, when Tom Roberts, Emily Abbott and Manny Azizi investigated the source of energy powering the jumps of three frog and toad species, they were surprised that the animals’ explosive launches were driven by plantaris longus muscle contractions of about the same power (~300 W kg^{-1}), even though Cuban tree frogs (*Osteopilus septentrionalis*) leapt with a take-off power of ~1100 W kg^{-1} while cane toads (*Bufo marinus*) achieved take-offs with a power of ~200 W kg^{-1}. Realising that the animals must be fine-tuning the energy storage capacity of the springy plantaris longus muscle–tendon unit, resulting in vastly different propulsion, Mendoza and Azizi scrutinised the legs of cane toads, Cuban tree frogs and bullfrogs (*Rana catesbeiana*) to determine how they differed.

‘All of our animals came from the pet trade’, says Mendoza, who collected samples of the animals’ plantaris longus muscle–tendon units to measure the amount of force exerted by the muscles as they contracted. ‘There are many challenges with this technique’, says Mendoza, such as keeping the muscle alive, making sure the nerve branch was not crushed or pulled too hard, and keeping the muscle–tendon unit securely in place in the force measuring rig. Then, she and Azizi investigated the structure of the frogs’ plantaris longus muscles, cutting the muscle open to reveal the featherlike arrangement of the fibres within to measure their stacking angle relative to the direction in which the muscle pulls (the pennation angle). Finally, the duo calculated how much work the muscle did during a contraction and the overall stiffness of the muscle–tendon unit to find out how much energy it could store.

After months of painstaking analysis, it was clear that the plantaris longus muscle–tendon unit of the Cuban tree frog stood out from the crowd. ‘It was modified for increased elastic energy storage’, says Mendoza, explaining that the structure is stiffer than that of the cane toad and bullfrog muscle–tendon unit, allowing the Cuban tree frogs to store more elastic energy to power their mighty leaps. In addition, when Mendoza and Azizi measured the force generated by the tree frog’s muscle (~30 N g^{-1}), it was almost double that produced by the cane toad and bullfrog (~17 N g^{-1}).

But how was the tree frog’s muscle able to generate so much force when it was so much smaller (~0.3 g) than the bullfrog and cane toad’s muscles (~1.3 and ~1 g, respectively)? Scrutinising the muscle structures, the duo realised that the muscle fibres in the Cuban tree frog plantaris longus were stacked at a much steeper angle (~25 deg compared with the cane toad and bullfrog’s 20 deg pennation angle), allowing the tree frogs to pack more fibres into the muscle to generate more force.

‘A tuned increase in muscle force and elastic structure stiffness increases elastic energy storage in Cuban tree frogs’, says Mendoza, and Azizi adds, ‘In terms of jump distance, Cuban tree frogs are the best, followed by bullfrogs and then cane toads’. So, the Cuban tree frog’s springier legs tie in nicely with their exceptional vaulting abilities.

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