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MEDIA RELEASE

UP-led study suggests declining energy efficiency of heart imposes upper limit on body size

PRETORIA – A groundbreaking study undertaken by researchers from the University of Pretoria's (UP) Faculty of Veterinary Science has revealed that the heart operates with declining energy efficiency as body size increases among mammals.

This means that larger mammals have hearts that lose relatively more energy as heat, rather than directing that energy to the blood so that it circulates around the body. A tiny shrew, therefore, has a more efficient heart than that of a large elephant. The implication is that eventually an upper limit on body size will be reached, where the heart is so inefficient at pumping blood, that it is no longer viable to do so. A gigantic 100-tonne sauropod, or any large-sized member of the dinosaur group Sauropoda, may represent this upper limit on body size.

The UP-led study, which was published today in the *Proceedings of the Royal Society B*, was conducted in collaboration with scientists from the University of Adelaide and Monash University in Australia, and the University of British Columbia in Canada.

The researchers assessed the hearts of mammals across a broad range of body size – from a shrew to an elephant, as well as many species in between – and realised they could use the relative densities of capillaries and mitochondria in the walls of the heart to determine the metabolic power of the cardiac tissue. "Capillaries and mitochondria are important because they are involved in the supply and consumption of fuel and oxygen that generate the energy the heart needs to pump blood around the body," Dr Ned Snelling, experimental physiologist at UP, explains.

The researchers found that the densities of the capillaries and mitochondria in the walls of the heart decrease in larger mammals. Dr Snelling explains that this was expected because heart rate also decreases with body size. "A large elephant may have a heart rate of about 30 beats per minute, but a tiny shrew can have a heart rate of well over 1 000 beats per minute!"

The scientists then compared the metabolic power of the heart against its mechanical power, which is measured as the energy imparted to the blood as it is pushed through the major vessels. They were surprised to discover a mismatch between the heart's metabolic power and its mechanical power. Because this mismatch increases with body size, it means the heart appears to operate with a declining efficiency in larger mammals than in smaller ones.

The implication is that as mammals increase in body size, they appear to be investing disproportionately more metabolic power into the heart, relative to the mechanical power imparted to the blood exiting the heart. "In terms of energy, larger mammals put more in, but get less out," Dr Snelling says. In larger mammals, the heart appears to become less efficient at using energy in the fuel delivered to the cells of the heart (primarily fatty acids) and converting it into energy in the blood exiting the heart (primarily blood pressure). In other words, the heart becomes less "energy efficient" in larger mammals with larger hearts.

"The heart is a bit like the motor in a car: it uses fuel and oxygen to make it run and do work for us, but a lot of that energy is wasted as heat, and it does no work for us," Dr Snelling explains. "Just like larger motors in larger cars appear less efficient, so too do larger hearts in larger mammals."

The researchers wanted to put more precise values on this decline in energy efficiency. By taking known values from humans, they showed that across the body size range of their data, the efficiency of the heart decreases from 44% in a 2g shrew to 19% in a six-tonne elephant. "By cautious extrapolation, we can estimate that a sauropod, weighing 100 tonnes or more, would have operated a heart with an efficiency in the region of only 15 to 17%," Dr Snelling says. This means that of all the energy used by the heart, only this small percentage is imparted to the blood so that it flows around the body. The rest is lost as heat.

The scientists do not know at what body size the efficiency of the heart might become so poor that it is no longer viable. They suggest that because of the complexity with which animals interact with their environment, there is unlikely to be an exact cut-off body weight, but rather a broad body weight range where the benefits of being big no longer pay off. That range probably overlaps to include the 100-tonne body size of the gigantic sauropods.

Dr Snelling says that for centuries, scientists and philosophers have been debating the maximum possible size of animals. "In the 1600s, Galileo Galilei argued that the 100-tonne blue whale could reach its size only because it is supported by water. But in the early 1900s, doubt was cast on this idea after palaeontologists unearthed a gigantic sauropod dinosaur, the 70-tonne *Brachiosaurus*. More recently, parts of other colossal sauropods have been uncovered, and some estimates place these species in the vicinity of 70 to 100 tonnes."

The traditional theory has been that 100 tonnes must be close to the maximum size that is physically possible, at least for land animals, because larger weights could not be supported by the strength of the bones and the forces of the muscles. "In effect, larger animals would be crushed by their own body weight," Dr Snelling adds. "Therefore, it is likely that gigantic sauropods were so restricted by their own weight that they struggled to move and could walk only at a slow, lumbering pace. But when you're this big, who is going to chase you? The disproportionate burden of gravity on larger animals is evident even today – it explains how a mouse can gallop, leap and jump, whereas an elephant can do none of these things."

The new research offers an alternative possibility: that it is declining energy efficiency of the heart that imposes an upper limit on body size. See link to article:
http://rspb.royalsocietypublishing.org/lookup/doi/10.1098/rspb.2021.2461

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Images:

Image 1: Upper limits to body size (from left to right): The 20-tonne extinct giant hornless rhino, *Indricotherium*, is one of the largest known land mammals to have existed; 70- to 100-tonne gigantic sauropods, such as Brachiosaurus, were the largest known animals to have walked the Earth; a very brave 60kg human for scale; the six-tonne African bush elephant is the largest land animal alive today. Credit: EP Snelling, with permission.

Image 2: A magnified image of cardiac tissue captured from the heart of a wild African antelope, the common duiker (*Sylvicapra grimmia*), showing the close functional relationship between the capillaries that supply fuel and oxygen (17 large tubular profiles flushed of blood) and mitochondria that consume fuel and oxygen (numerous dark-stained structures). Credit: EP Snelling, with permission.

Image 3: How the densities of capillaries and mitochondria in the wall of the heart change across five orders of magnitude in body weight among mammals, from shrew to elephant. Credit: EP Snelling, with permission.

Image 4: Composite showing a magnified image of cardiac tissue where fuel and oxygen enter the cells; an image of the heart pump that pressurises the blood; phylogeny of species used in the study; and the body size relationships of the capillaries and mitochondria (as a proxy for metabolic power) and mechanical power of the heart. Credit: EP Snelling, with permission.

About the University of Pretoria

The University of Pretoria (UP) is one of the largest contact and residential universities in South Africa, with its administration offices located on the Hatfield Campus, Pretoria. This 113-year-old institution is also the largest producer of research in South Africa.

Spread over seven campuses, it has nine faculties and a business school, the Gordon Institute of Business Science (GIBS). It is the only University in the country with a Faculty of Veterinary Science, which is ranked top in Africa. UP has 120 academic departments and 92 centres and institutes, accommodating more than 55 000 students and offering about 1 100 study programmes.

UP is one of the top five universities in South Africa, according to the 2019-2020 rankings by the Center for World University Rankings. The QS World University Rankings also placed UP among the top 100 universities worldwide in three fields of study (veterinary science, theology and law), and UP is in the top 1% in eight fields of study (agricultural sciences, clinical medicine, engineering, environment/ecology, immunology, microbiology, plant and animal sciences and social sciences), according to the Web of Science Essential Indicators.

In May 2020, the annual UK Financial Times Executive Education Rankings again ranked GIBS as the top South African and African business school. The University also has an extensive community engagement programme with approximately 33,000 students involved in community upliftment. Furthermore, UP is building considerable capacities and strengths for the Fourth Industrial Revolution by preparing students for the world beyond university and offering work-readiness and entrepreneurship training.

As one of South Africa's research-intensive universities, UP launched the Future Africa Campus in March 2019 as a hub for inter- and transdisciplinary research networks within UP and the global research community to maximise 4IR innovation and address the challenges and stresses our continent and world is facing. In addition, UP also launched the Javett Art Centre in September 2019 as a driver of transdisciplinary research development between the Humanities and other faculties. In November 2020 UP launched Engineering 4.0. as a hub not only for Smart Cities and Transport, but also to link the vast resources in technology and data sciences to other faculties via Future Africa. These initiatives are stimulating new thinking at the frontier of 'science for transformation'.

For more information, go to www.up.ac.za