Vertebrate Functional Morphology and Physiology

Introductory article

Article Contents

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Functional morphology is the study of the design of tissues and organ systems, the principles of physics affecting animals, and the mechanisms of the body. Physiology is the study of how living organisms adjust to their environments and regulate critical functions at the tissue, system, cellular and molecular levels. Together the two related fields include a broad range of topics such as feeding mechanics, digestion, locomotion, muscle contraction, circulatory design, oxygen exchange and other topics focused on animal function.

Morphology, Physiology and Function: How Animals Work

Why are animals built like they are, and how do they work? Functional morphology and physiology are related areas of study that reveal how animals move, breathe, eat, digest, reproduce and gather sensory information in their environments. These two areas of inquiry cover a broad range of organic functions, from detailed physiology such as ion exchange across cell membranes to large-scale biomechanics such as the physics of elephant locomotion. Classical topics in physiology include mechanisms of exchanging oxygen across respiratory membranes for breathing, the breakdown of foods into metabolic energy during digestion, the responses of animals to temperature changes, the control of hormones to regulate reproductive cycles, and the function of eyes, ears and tongue to gather sensory information about the environment. Functional morphology spans a broad range of ideas in biology that focus on the design of systems in animals. Functional morphologists might study the compressive strength of bone cells, the forces on animals from gravity or fluid motion, the streamlined shapes of aquatic animal bodies and aerial wings, and the mechanisms by which muscles contract, skeletons move and behaviour is generated. Together, physiology and functional morphology explain how animals are designed to do the vast array of things that they do.

Mechanical Design in Vertebrates

The bodies of vertebrate animals can be thought of as finely engineered devices for growth, survival and reproduction. Engineered by evolution, vertebrates have diversified into a spectacular array of body plans for performing the daily functions of feeding and locomotion as well as the critical needs for escape, survival of environmental extremes, and finding mates. Consider the mechanical designs of a tuna fish and an albatross, a large seabird. Both are specialized for high-speed locomotion in different environments with quite different physical demands. The tuna body is streamlined for easy passage through the water, and generates propulsion with a moon-shaped tail specialized for high thrust forces (**Figure 1**). The albatross body is slender with long, narrow wings that give it exceptional gliding ability and allow it to stay in the air for days at a time (**Figure 1**). The body size and structure of these animals

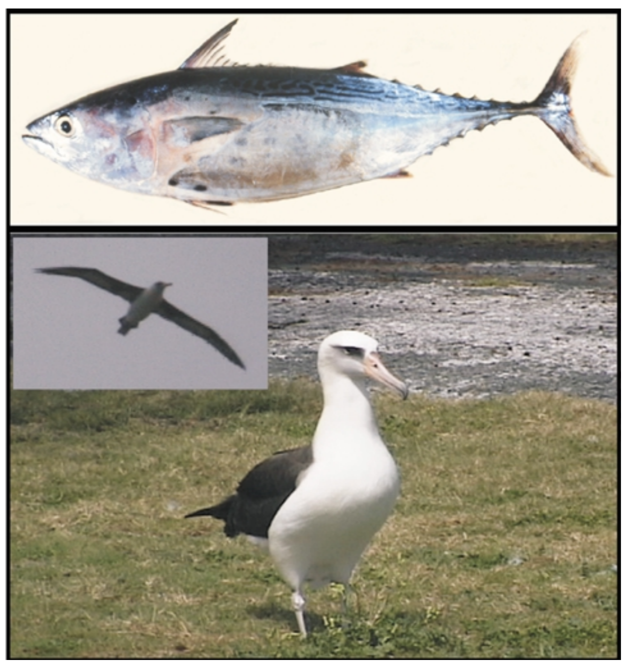

Figure 1 Mechanical design in vertebrates, illustrated by the streamlined body and propeller-like tail of the tuna and the long, narrow wings of the albatross – two designs for rapid, efficient locomotion.

is matched with the properties of water and air to enable the tuna and albatross to move swiftly through ocean and sky.

The mechanical design of systems within animals is a central topic in functional morphology. For example, the structure of muscles and bones in the jaws of vertebrates reflects the means by which food is captured. The jaws of fishes are designed differently from the jaws of mammals, in part because of the requirements for feeding in aquatic versus terrestrial habitats. A sabre-toothed characin (**Figure 2**) is capable of generating suction to capture prey as well as impale prey upon its large canine teeth in its slender lower jaw. The jaws of a hippopotamus (**Figure 2**) are massive bones armed with large canines in the lower jaw for rooting through the mud for food and forking up large mouthfuls of aquatic vegetation. Large teeth are a common feature of these two vertebrates, but jaw design and feeding mechanics are tuned to the special ways of life of the two different animals.

Physiological Responses of Vertebrates

How do muscles contract? How do gills and lungs transport oxygen? Why do birds excrete white uric acid instead of water-based urine like we do? These are questions of animal physiology. Animals constantly face the need to balance bodily functions with environmental conditions. A fish must obtain enough food energy, oxygen and water to survive, yet too much water or oxygen in the body of any animal can be fatal. Wild horses and dogs generate heat internally as a mechanism of survival during cold weather, but without sweating (horses) or panting (dogs) that same heat generation would cause stress and even death on warm days. Achieving the proper balance of nutrition, oxygen, water and temperature is common to all living vertebrates. The mechanisms for this balance are diverse among animals and constitute a central area of physiology.

The complex interactions of structure function, and molecular mechanisms in physiology are illustrated by exploring the first question above regarding muscle contraction. The structure of muscle (**Figure 3**) consists of a group of muscle fibres organized into a sheet or widened

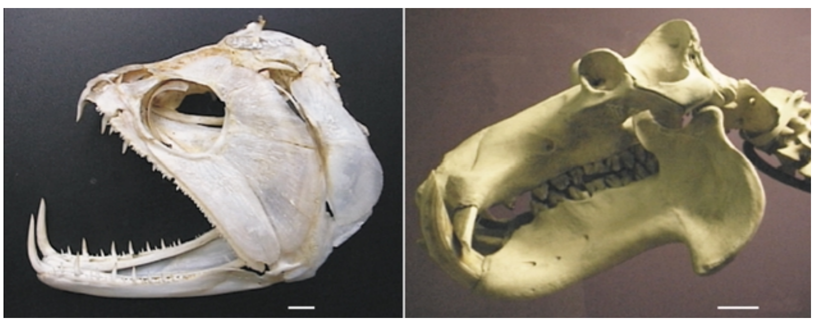

Figure 2 Large canine teeth in the lower jaw are shared by the sabre-toothed characin (left: scale, 1 cm) and the hippopotamus (right: scale, 10 cm). The teeth and jaws function in very different ways: the fish uses fast jaw motions to impale evasive prey whereas the hippopotamus forcefully digs for vegetation with its powerful jaws and heavy teeth.

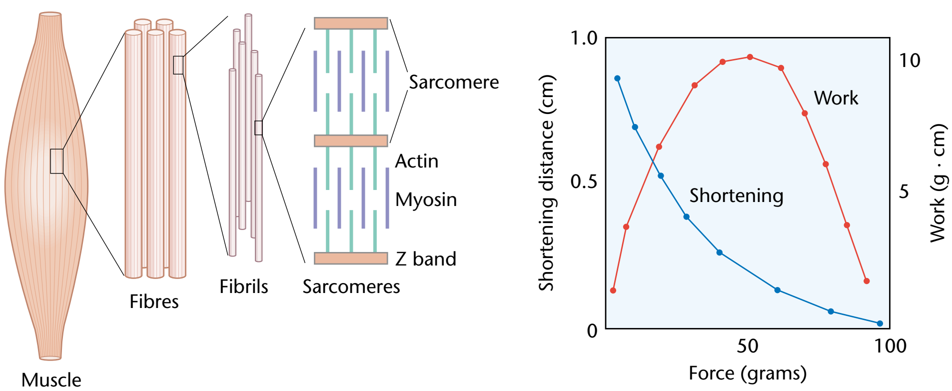

Figure 3 The structure of muscle (left) at levels ranging from gross morphology, muscle fibres, fibrils, and the actin and myosin molecules that slide along one another to produce contraction. Muscle contraction produces the physiological plots (right) of shortening distance, force production, and work that a muscle can perform.

cylinder of muscle. Muscle fibres are built from groups of muscle fibrils, which have lighter and darker bands along their length. These bands are formed from a regularly repeating arrangement of overlapping thick and thin filaments, called actin and myosin. The thick and thin filaments are connected by a system of molecular cross-linkages. When the muscle contracts, it does so because these crosslinkages are rearranged so that the two types of filament slide along each other, reducing the distance between Z bands. The shortening of muscle produces force that operates over a certain distance to produce work (**Figure 3**). For most vertebrate muscles, the maximum amount of work is accomplished in the central range of muscle shortening. The combination of molecular mechanisms, muscle microstructure and the muscle acting upon a vertebrate skeleton determines the specific amount of shortening, work and power that a muscle is capable of generating.

Integration of Structure, Function and Physiology

One of the great frontiers of biology is an integrated, complete understanding of how animals are built and function in order to survive and perform the spectacular array of behaviours that we see in nature. Physiology and functional morphology are relevant at scales ranging from molecular structure and action in cells to the muscular thrust of the tail of a sperm whale. Combining discoveries among levels of design and across a diversity of animals will reveal central principles of animal function and evolution.

Further Reading

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