Lever Mechanics and Feeding Diversity in Carnivora

Mammals chew. This may seem banal to you, but it is actually quite different from the way most vertebrates use their jaws -- in these species, the jaws capture and hold prey until it can be swallowed whole, and teeth (if present at all) are sets of nearly identical cones. Mammals can use their jaws to capture and hold prey, but they also use them to process food into a more digestable paste. As a result, mammalian teeth often look different as you move from the front of the mouth toward the back, because they are specialized for different jobs.

Parts of the Skull

Before we move on to carnivore jaw diversity, take the time to familiarize yourself with some of the parts of a mammalian skull. There are two main sections: the mandible, or lower jaw, which in living mammals is made up of one bone, the dentary, and the cranium, which includes many bones making up the upper jaw and the braincase. Teeth are found on both the mandible and the front part of the cranium, and follow a general front-to-back pattern: incisors, canines, premolars, and molars.

Mammals have two major jaw-closing muscles: the masseter and the temporalis. The masseter is the muscle that makes up the "cheek" and runs from the region of the cranium immediately below the eye to the rear of the mandible. The temporalis covers the side of the braincase and runs to the rear of the mandible. Contraction of these muscles moves the mandible up to contact the upper jaw and produce the bite.
Carnivores and their jaws

The order Carnivora radiated from a meat-eating ancestor that lived about 60 million years ago into a vast array of modern species. Modern members belong to one of two large groups: the caniform ("dog-like") and the feliform ("cat-like"). Caniform taxa include the canids (dogs), ursids (bears), mustelids (weasels, skunks, and their kin), procyonids (raccoons and kinkajous), and the pinnipeds (sea lions and seals); feliform taxa include the felids (cats), hyaenids, viverrids, and herpisteds (mongooses and their ilk). Carnivora does not contain all carnivorous (meat-eating) mammals, and in fact not all Carnivora are exclusively meat-eating -- many modern members of the order are omnivores, and a few are completely herbivorous. Membership in the order Carnivora depends on descent from a common ancestor, not food preferences.

Members of Carnivora are distinguished by their enlarged fourth upper premolar and first lower molar, which together form the carnassial teeth. Carefully open the jaw of one of the canid or felid skulls in the lab and find its carnassials. Now gently close the jaws and watch how the premolar and molar slice past one another -- this dentition is unique to carnivores, and is very effective at cutting through meat and tendon. Carnassial shearing is so important to these animals that they have lost the ability to move their jaws from side-to-side (as you can), in order to keep the carnassial teeth close together during chewing.

Once you've indentified the carnassials, look for them on the other skulls in the room. Are they the same shape in every species? How does the shape of the skull and jaw vary among species and among larger groups of carnivore? Are the shape changes correlated with size, diet, or some other factor?

Jaw mechanics

The jaw can be viewed as a lever system for applying force to food. A lever consists of a pivot point (the jaw articulation), and two lever arms. The in-lever arm connects the pivot to the point where an “in-force” (F_i) is applied by a muscle. The out-lever arm connects the pivot to the
point where an “out-force” \( (F_o) \) is applied by the teeth to the food. As a general rule, the out-force can be increased by decreasing the length of the out-lever arm and increasing the length of the in-lever arm. The force-multiplying effect of a lever is characterized by its mechanical advantage:

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\text{Mechanical Advantage} = \frac{F_o}{F_i} = \frac{\text{length of in-lever arm}}{\text{length of out-lever arm}}
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The higher the mechanical advantage, the greater the out-force, or in this case, the bite force. Because the temporalis and the masseter are the major jaw-closing muscles in mammals, they are the source of forces on the mandible during chewing. We’ll focus on the masseter today, but you'll be asked to develop and test your own hypothesis around temporalis function next week.

As a measure of its in-lever arm we’ll use the distance from the jaw articulation to the bottom of the angular process, and we’ll call this distance the Masseter In-Lever Arm, or MILA. As a measure of the out-lever arm for the chewing teeth, we’ll use the distance from the jaw articulation to the middle of the tooth row, which can be taken as the middle cusp of the last premolar. We’ll call this the Chewing Out-Lever Arm, or COLA. The mechanical advantage of the jaw can be calculated as the MILA/COLA.

Choose a set of skulls to measure (all the skulls will be members of one carnivore family). Measure the MILA and COLA of each jaw with calipers, and calculate the mechanical advantage for
each jaw. Because the skulls you're examining are different sizes, you'll also have to determine the scaling relationships of the jaws: plot log(MILA) on the y-axis against the log(COLA) on the x-axis, analyze the shape of the curve, and calculate the slope (scaling exponent) if appropriate.

Consider the following questions:
Do the jaws of larger individuals differ in shape from those of smaller ones, and if so, how?
Does a power function describe the size-shape pattern?
Is the scaling of the jaws isometric or allometric within your carnivore family?
How does mechanical advantage vary with size?
Are there any strange outliers in your family? Do they eat something very different from other members of their family? What are some functional implications of jaw shape?

For next week, we would like you (in a group of 3-4 people) to prepare a hypothesis (and an experiment to test it) based on the mechanical advantage of the carnivore jaw when it is moved by the temporalis muscle. The temporalis is the primary muscle that closes the jaw in Carnivora; it originates on the side of the braincase, and inserts on the rear of the mandible. You will need to decide how to measure the Temporalis In-Lever Arm (TILA) so you can calculate the muscle's mechanical advantage and scaling relationships. At the end of this week's lab, please turn in your group's hypothesis and a brief description of how you propose to test it (including the species you plan to measure, how many skulls of each species, and which measurements you plan to make).

Feeling lost? In today's exercise, we looked at changes in mechanical advantage and size within one family of carnivores. When thinking about possible hypotheses you may want to consider the diversity of skull shape among different carnivore families, and how that might affect the mechanical advantage of the jaw. Or consider species of carnivore that have become omnivorous, or herbivorous, or piscivorous (fish eating) -- does their change in diet affect their jaws in a particular way? You will write up this experiment as a full lab report in scientific format -- describing the major differences among the skulls you've chosen, and presenting both your hypothesis and your analysis of the skulls.

Literature Cited: