The Comparative Anatomy of Eating

by Milton R. Mills, M.D.

Humans are most often described as "omnivores." This classification is based on the "observation" that humans generally eat a wide variety of plant and animal foods. However, culture, custom and training are confounding variables when looking at human dietary practices. Thus, "observation" is not the best technique to use when trying to identify the most "natural" diet for humans. While most humans are clearly "behavioral" omnivores, the question still remains as to whether humans are anatomically suited for a diet that includes animal as well as plant foods.

A better and more objective technique is to look at human anatomy and physiology. Mammals are anatomically and physiologically adapted to procure and consume particular kinds of diets. (It is common practice when examining fossils of extinct mammals to examine anatomical features to deduce the animal's probable diet.) Therefore, we can look at mammalian carnivores, herbivores (plant-eaters) and omnivores to see which anatomical and physiological features are associated with each kind of diet. Then we can look at human anatomy and physiology to see in which group we belong.

Oral Cavity

Carnivores have a wide mouth opening in relation to their head size. This confers obvious advantages in developing the forces used in seizing, killing and dismembering prey. Facial musculature is reduced since these muscles would hinder a wide gape, and play no part in the animal's preparation of food for swallowing. In all mammalian carnivores, the jaw joint is a simple hinge joint lying in the same plane as the teeth. This type of joint is extremely stable and acts as the pivot point for the "lever arms" formed by the upper and lower jaws. The primary muscle used for operating the jaw in carnivores is the temporalis muscle. This muscle is so massive in carnivores that it accounts for most of the bulk of the sides of the head (when you pet a dog, you are petting its temporalis muscles). The "angle" of the mandible (lower jaw) in carnivores is small. This is because the muscles (masseter and pterygoids) that attach there are of minor importance in these animals. The lower jaw of carnivores cannot move forward, and has very limited side-to-side motion. When the jaw of a carnivore closes, the blade-shaped cheek molars slide past each other to give a slicing motion that is very effective for shearing meat off bone.

The teeth of a carnivore are discretely spaced so as not to trap stringy debris. The incisors are short, pointed and prong-like and are used for grasping and shredding. The canines are greatly elongated and dagger-like for stabbing, tearing and killing prey. The molars (carnassials) are flattened and triangular with jagged edges such that they function like serrated-edged blades. Because of the hinge-type joint, when a carnivore closes its jaw, the cheek teeth come together in a back-to-front fashion giving a smooth cutting motion like the blades on a pair of shears.

The saliva of carnivorous animals does not contain digestive enzymes. When eating, a mammalian carnivore gorges itself rapidly and does not chew its food. Since proteolytic (protein-digesting) enzymes cannot be liberated in the mouth due to the danger of autodigestion (damaging the oral cavity), carnivores do not need to mix their food with saliva; they simply bite off huge chunks of meat and swallow them whole.

According to evolutionary theory, the anatomical features consistent with an herbivorous diet represent a more recently derived condition than that of the carnivore. Herbivorous mammals have well-developed facial musculature, fleshy lips, a relatively small opening into the oral cavity and a thickened, muscular tongue. The lips aid in the movement of food into the mouth and, along with the facial (cheek) musculature and tongue, assist in the chewing of food. In herbivores, the jaw joint has moved to position above the plane of the teeth. Although this type of joint is less stable than the hinge-type joint of the carnivore, it is much more mobile and allows the complex jaw motions needed when chewing plant foods. Additionally, this type of jaw joint allows the upper and lower cheek teeth to come together along the length of the jaw more or less at once when the mouth is closed in order to form grinding platforms. (This type of joint is so important to a plant-eating animal, that it is believed to have evolved at least 15 different times in various plant-eating mammalian species.) The angle of the mandible has expanded to provide a broad area of attachment for the well-developed masseter and pterygoid muscles (these are the major muscles of chewing in plant-eating animals). The temporalis muscle is small and of minor importance. The masseter and pterygoid muscles hold the mandible in a sling-like arrangement and swing the jaw from side-to-side. Accordingly, the lower jaw of plant-eating mammals has a pronounced sideways motion when eating. This lateral movement is necessary for the grinding motion of chewing.

The dentition of herbivores is quite varied depending on the kind of vegetation a particular species is adapted to eat. Although these animals differ in the types and numbers of teeth they possess, the various kinds of teeth when present, share common structural features. The incisors are broad, flattened and spade-like. Canines may be small as in horses, prominent as in hippos, pigs and some primates (these are thought to be used for defense) or absent altogether. The molars, in general, are squared and flattened on top to provide a grinding surface. The molars cannot vertically slide past one another in a shearing/slicing motion, but they do horizontally slide across one another to crush and grind. The surface features of the molars vary depending on the type of plant material the animal eats. The teeth of herbivorous animals are closely grouped so that the incisors form an efficient cropping/biting mechanism, and the upper and lower molars form extended platforms for crushing and grinding. The "walled-in" oral cavity has a lot of potential space that is realized during eating.

These animals carefully and methodically chew their food, pushing the food back and forth into the grinding teeth with the tongue and cheek muscles. This thorough process is necessary to mechanically disrupt plant cell walls in order to release the digestible intracellular contents and ensure thorough mixing of this material with their saliva. This is important because the saliva of plant-eating mammals often contains carbohydrate-digesting enzymes which begin breaking down food molecules while the food is still in the mouth.

Stomach and Small Intestine

Striking differences between carnivores and herbivores are seen in these organs. Carnivores have a capacious simple (single-chambered) stomach. The stomach volume of a carnivore represents 60-70% of the total capacity of the digestive system. Because meat is relatively easily digested, their small intestines (where absorption of food molecules takes place) are short—about three to five or six times the body length. Since these animals average a kill only about once a week, a large stomach volume is advantageous because it allows the animals to quickly gorge themselves when eating, taking in as much meat as possible at one time which can then be digested later while resting. Additionally, the ability of the carnivore stomach to secrete hydrochloric acid is exceptional. Carnivores are able to keep their gastric pH down around 1-2 even with food present. This is necessary to facilitate protein breakdown and to kill the abundant dangerous bacteria often found in decaying flesh foods.

Because of the relative difficulty with which various kinds of plant foods are broken down (due to large amounts of indigestible fibers), herbivores have significantly longer and in some cases, far more elaborate guts than carnivores. Herbivorous animals that consume plants containing a high proportion of cellulose must "ferment" (digest by bacterial enzyme action) their food to obtain the nutrient value. They are classified as either "ruminants" (foregut fermenters) or hindgut fermenters. The ruminants are the

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plant-eating animals with the celebrated multiple-chambered stomachs. Herbivorous animals that eat a diet of relatively soft vegetation do not need a multiple-chambered stomach. They typically have a simple stomach, and a long small intestine. These animals ferment the difficult-to-digest fibrous portions of their diets in their hindguts (colons). Many of these herbivores increase the sophistication and efficiency of their GI tracts by including carbohydrate-digesting enzymes in their saliva. A multiple-stomach fermentation process in an animal which consumed a diet of soft, pulpy vegetation would be energetically wasteful. Nutrients and calories would be consumed by the fermenting bacteria and protozoa before reaching the small intestine for absorption. The small intestine of plant-eating animals tends to be very long (greater than 10 times body length) to allow adequate time and space for absorption of the nutrients.

Colon

The large intestine (colon) of carnivores is simple and very short, as its only purposes are to absorb salt and water. It is approximately the same diameter as the small intestine and, consequently, has a limited capacity to function as a reservoir. The colon is short and non-pouched. The muscle is distributed throughout the wall, giving the colon a smooth cylindrical appearance. Although a bacterial population is present in the colon of carnivores, its activities are essentially putrefactive.

In herbivorous animals, the large intestine tends to be a highly specialized organ involved in water and electrolyte absorption, vitamin production and absorption, and/or fermentation of fibrous plant materials. The colons of herbivores are usually wider than their small intestine and are relatively long. In some plant-eating mammals, the colon has a pouched appearance due to the arrangement of the muscle fibers in the intestinal wall. Additionally, in some herbivores the cecum (the first section of the colon) is quite large and serves as the primary or accessory fermentation site.

What About Omnivores?

One would expect an omnivore to show anatomical features which equip it to eat both animal and plant foods. According to evolutionary theory, carnivore gut structure |is more primitive than herbivorous adaptations. Thus, an omnivore might be expected to be a carnivore which shows some gastrointestinal tract adaptations to an herbivorous diet.

This is exactly the situation we find in the Bear, Raccoon and certain members of the Canine families. (This discussion will be limited to bears because they are, in general, representative of the anatomical omnivores.) Bears are classified as carnivores but are classic anatomical omnivores. Although they eat some animal foods, bears are primarily herbivorous with 70-80% of their diet comprised of plant foods. (The one exception is the Polar bear which lives in the frozen, vegetation poor arctic and feeds primarily on seal blubber.) Bears cannot digest fibrous vegetation well, and therefore, are highly selective feeders. Their diet is dominated by primarily succulent lent herbage, tubers and berries. Many scientists believe the reason bears hibernate is because their chief food (succulent vegetation) not available in the cold northern winters. (Interestingly, Polar bears hibernate during the summer months when seals are unavailable.)

In general, bears exhibit anatomical features consistent with a carnivorous diet. The jaw joint of bears is in the same plane as the molar teeth. The temporalis muscle is massive, and the angle of the mandible is small corresponding to the limited role the pterygoid and masseter muscles play in operating the jaw. The small intestine is short (less than five times body length) like that of the pure carnivores, and the colon is simple, smooth and short. The most prominent adaptation to an herbivorous diet in bears (and other "anatomical" omnivores) is the modification of their dentition. Bears retain the peg-like incisors, large canines and shearing premolars of a carnivore; but the molars have become squared with rounded cusps for crushing and grinding. Bears have not, however, adopted the flattened, blunt nails seen in most herbivores and retain the elongated, pointed claws of a carnivore.

An animal which captures, kills and eats prey must have the physical equipment which makes predation practical and efficient. Since bears include significant amounts of meat in their diet, they must retain the anatomical features that permit them to capture and kill prey animals. Hence, bears have a jaw structure, musculature and dentition which enable them to develop and apply the forces necessary to kill and dismember prey even though the majority of their diet is comprised of plant foods. Although an herbivore-style jaw joint (above the plane of the teeth) is a far more efficient joint for crushing and grinding vegetation and would potentially allow bears to exploit a wider range of plant foods in their diet, it is a much weaker joint than the hinge-style carnivore joint. The herbivore-style jaw joint is relatively easily dislocated and would not hold up well under the stresses of subduing struggling prey and/or crushing bones (nor would it allow the wide gape carnivores need). In the wild, an animal with a dislocated jaw would either soon starve to death or be eaten by something else and would, therefore, be selected against. A given species cannot adopt the weaker but more mobile and efficient herbivore-style joint until it has committed to an essentially plant-food diet test it risk jaw dislocation, death and ultimately, extinction.

What About Me?

The human gastrointestinal tract features the anatomical modifications consistent with an herbivorous diet. Humans have muscular lips and a small opening into the oral cavity. Many of the so-called "muscles of expression" are actually the muscles used in chewing. The muscular and agile tongue essential for eating, has adapted to use in speech and other things. The mandibular joint is flattened by a cartilaginous plate and is located well above the plane of the teeth. The temporalis muscle is reduced. The characteristic "square jaw" of adult males reflects the expanded angular process of the mandible and the enlarged masseter/pterygoid muscle group. The human mandible can move forward to engage the incisors, and side-to-side to crush and grind.

Human teeth are also similar to those found in other herbivores with the exception of the canines (the canines of some of the apes are elongated and are thought to be used for display and/or defense). Our teeth are rather large and usually abut against one another. The incisors are flat and spade-like, useful for peeling, snipping and biting relatively soft materials. The canines are neither serrated nor conical, but are flattened, blunt and small and function Like incisors. The premolars and molars are squarish, flattened and nodular, and used for crushing, grinding and pulping non-coarse foods.

Human saliva contains the carbohydrate-digesting enzyme, salivary amylase. This enzyme is responsible for the majority of starch digestion. The esophagus is narrow and suited to small, soft balls of thoroughly chewed food. Eating quickly, attempting to swallow a large amount of food or swallowing fibrous and/or poorly chewed food (meat is the most frequent culprit) often results in choking in humans.

Man's stomach is single-chambered, but only moderately acidic. (Clinically, a person presenting with a gastric pH less than 4-5 when there is food in the stomach is cause for concern.) The stomach volume represents about 21-27% of the total volume of the human GI tract. The stomach serves as a mixing and storage chamber, mixing and liquefying ingested foodstuffs and regulating their entry into the small intestine. The human small intestine is long, averaging from 10 to 11 times the body length. (Our small intestine averages 22 to 30 feet in length. Human body size is measured from the top of the head to end of the spine and averages between two to three feet in length in normal-sized individuals.)

> **"The large intestine (colon) of carnivores is simple and very short...the colons of herbivores are usually wider than their small intestine and are relatively long."**

The human colon demonstrates the pouched structure peculiar to herbivores. The distensible large intestine is larger in cross-section than the small intestine, and is relatively long. Man's colon is responsible for water and electrolyte absorption and vitamin production and absorption. There is also extensive bacterial fermentation of fibrous plant materials, with the production and absorption of significant amounts of food energy (volatile short-chain fatty acids) depending upon the fiber content of the diet. The extent to which the fermentation and absorption of metabolites takes place in the human colon has only recently begun to be investigated.

In conclusion, we see that human beings have the gastrointestinal tract structure of a "committed" herbivore. Humankind does not show the mixed structural features one expects and finds in anatomical omnivores such as bears and raccoons. Thus, from comparing the gastrointestinal tract of humans to that of carnivores, herbivores and omnivores we must conclude that humankind's GI tract is designed for a purely plant-food diet.

Summary

FACIAL MUSCLES

Carnivore	Reduced to allow wide mouth gape
Herbivore	Well-developed
Omnivore	Reduced
Human	Well-developed

JAW TYPE

Carnivore	Angle not expanded
Herbivore	Expanded angle
Omnivore	Angle not expanded
Human	Expanded angle

JAW JOINT LOCATION

Carnivore	On same plane as molar teeth
Herbivore	Above the plane of the molars
Omnivore	On same plane as molar teeth
Human	Above the plane of the molars

JAW MOTION

Carnivore	Shearing; minimal side-to-side motion
Herbivore	No shear; good side-to-side, front-to-back
Omnivore	Shearing; minimal side-to-side
Human	No shear; good side-to-side, front-to-back

MAJOR JAW MUSCLES

Carnivore	Temporalis
Herbivore	Masseter and pterygoids
Omnivore	Temporalis
Human	Masseter and pterygoids

MOUTH OPENING vs. HEAD SIZE

Carnivore	Large
Herbivore	Small
Omnivore	Large
Human	Small

TEETH (INCISORS)

Carnivore	Short and pointed
Herbivore	Broad, flattened and spade shaped
Omnivore	Short and pointed
Human	Broad, flattened and spade shaped

TEETH (CANINES)

Carnivore	Long, sharp and curved
Herbivore	Dull and short or long (for defense), or none
Omnivore	Long, sharp and curved
Human	Short and blunted

TEETH (MOLARS)

Carnivore	Sharp, jagged and blade shaped
Herbivore	Flattened with cusps vs complex surface
Omnivore	Sharp blades and/or flattened
Human	Flattened with nodular cusps

CHEWING

Carnivore	None; swallows food whole
Herbivore	Extensive chewing necessary
Omnivore	Swallows food whole and/or simple crushing
Human	Extensive chewing necessary

SALIVA

Carnivore	No digestive enzymes
Herbivore	Carbohydrate digesting enzymes
Omnivore	No digestive enzymes
Human	Carbohydrate digesting enzymes

STOMACH TYPE

Carnivore	Simple
Herbivore	Simple or multiple chambers
Omnivore	Simple
Human	Simple

STOMACH ACIDITY

Carnivore	Less than or equal to pH 1 with food in stomach
Herbivore	pH 4 to 5 with food in stomach
Omnivore	Less than or equal to pH 1 with food in stomach
Human	pH 4 to 5 with food in stomach

STOMACH CAPACITY

Carnivore	60% to 70% of total volume of digestive tract
Herbivore	Less than 30% of total volume of digestive tract
Omnivore	60% to 70% of total volume of digestive tract
Human	21% to 27% of total volume of digestive tract

LENGTH OF SMALL INTESTINE

Carnivore	3 to 6 times body length
Herbivore	10 to more than 12 times body length
Omnivore	4 to 6 times body length
Human	10 to 11 times body length

COLON

Carnivore	Simple, short and smooth
Herbivore	Long, complex; may be sacculated
Omnivore	Simple, short and smooth
Human	Long, sacculated

LIVER

Carnivore	Can detoxify vitamin A
Herbivore	Cannot detoxify vitamin A
Omnivore	Can detoxify vitamin A
Human	Cannot detoxify vitamin A

KIDNEY

Carnivore	Extremely concentrated urine
Herbivore	Moderately concentrated urine
Omnivore	Extremely concentrated urine
Human	Moderately concentrated urine

NAILS

Carnivore	Sharp claws
Herbivore	Flattened nails or blunt hooves
Omnivore	Sharp claws
Human	Flattened nails