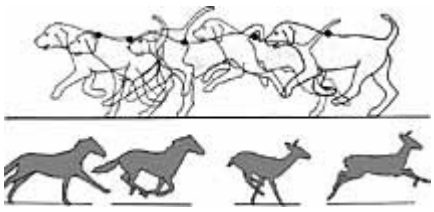
Anatomical Adaptation for Cursorial Locomotion

(Designed for Running)



Running is mainly about speed -- obtained by combining stride rate and stride length. Stride rate is favored by reducing limb mass (especially distally). Stride length is gained by increasing limb length (anatomically or physiologically). Rate and length are antagonistic, i.e., enhancing one compromises the other.

Domestic mammals exhibit cursorial (running) adaptations to varying degrees:

Carnivores require multipurpose limbs (both running & manupilating). Carnivores are fast because they have flexible trunks, which is possible because they have a meat diet (which is why they need multipurpose limbs in the first place).

Herbivores, with roughage diets and bulky abdominal viscera, have relatively limited trunk flexion, but their limbs are freed to be devoted entirely to locomotion. Equine limbs have become so specialized, they resemble "machines" (reliance more on bone & ligament and less nerve and muscle).

Thus locomotion and digestion are linked in evolution. This document considers:

- Anatomical adaptations for running (forelimb)
- Forelimb vs. hindlimb differences
- Carnivore vs. herbivore digestive tracts

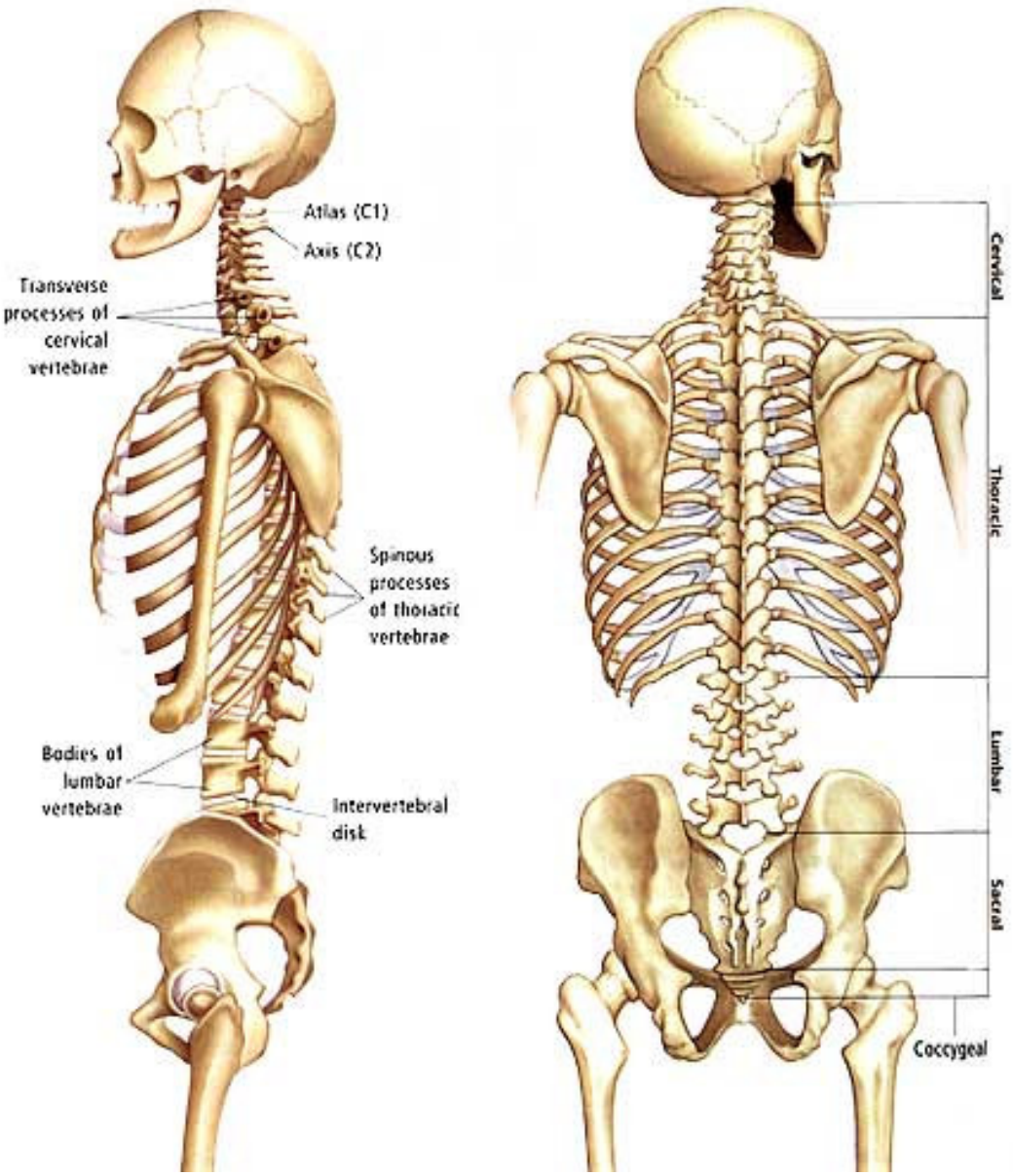
Muscle/Skeletal Specialization of Forelimbs

Anatomical limb design involves compromises between flexibility (rotation & dexterity) and stability (joint fixation & secure contact with a surface). Anatomical specialization has evolved to facilitate different functional roles, including the different roles of thoracic and pelvic limbs (compared below).

Generalized limb anatomy (evident in many mammals, reptiles, and birds)

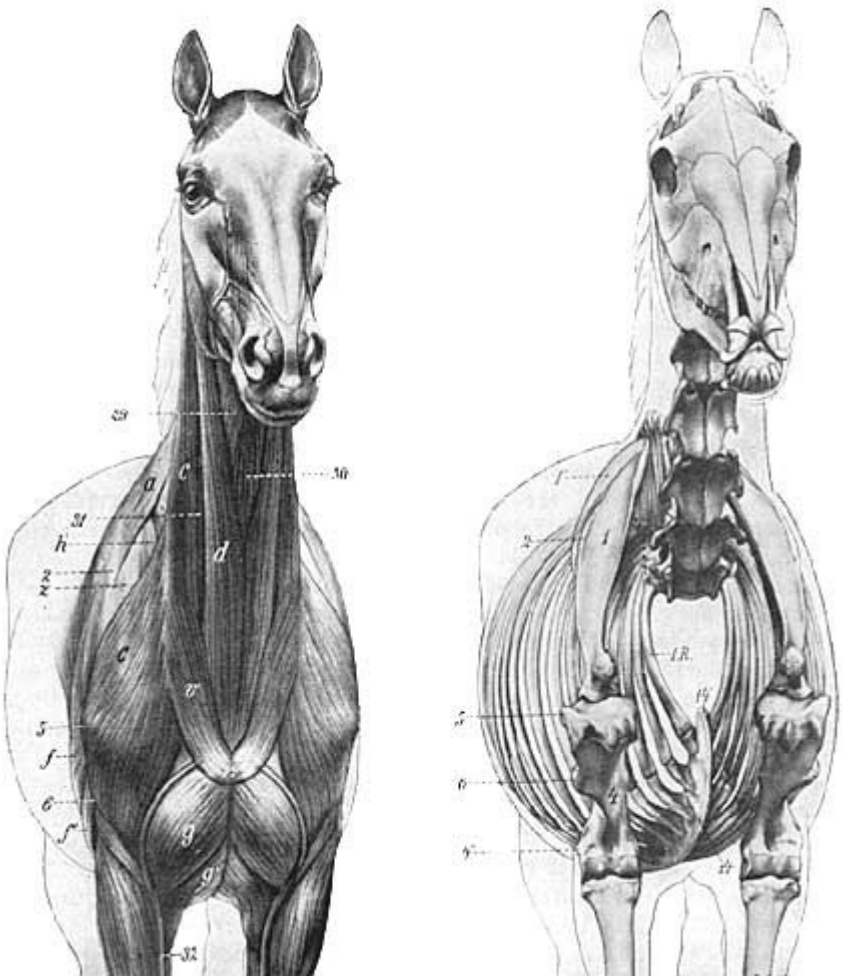
- scapula positioned dorsally on a flat back
- shoulder joint fixed & capable of circumduction (ball and socket joint)
- two bones in forearm, enabling rotation while providing stability
    - ulna firmly attached to the elbow (loosely attached to the wrist)
    - radius firmly attached to the wrist (loosely attached to the elbow)
- plantigrade contact with the ground
- multiple digits (typically five)
- unguis (nail, claw, hoof)

Human Skeleton



Notice that the chest is flattened dorsoventally, the scapula is positioned dorsally (on the back), and the distal end of the scapula is fixed (immobilized) by the clavicle.

EquineSkeleton

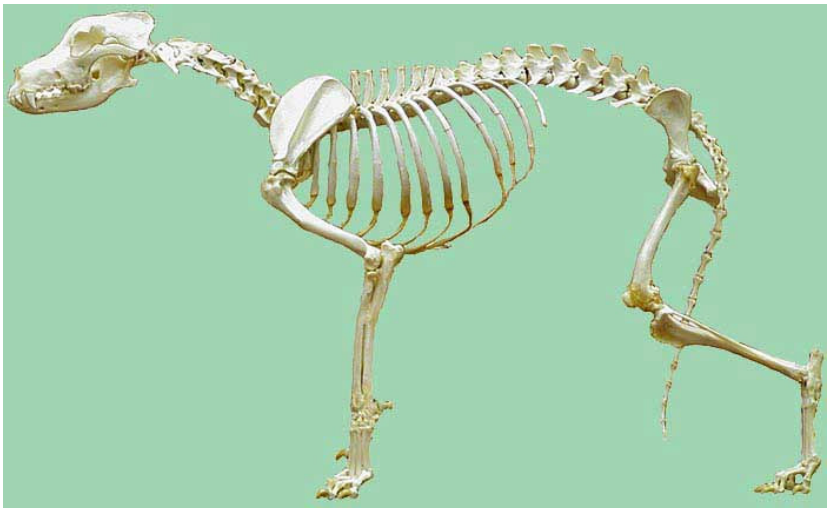


Notice that the chest is flattened mediolaterally, the scapula is positioned laterally on the thorax, and the distal end of the scapula is free to move (the clavicle bone is absent).

Limb adaptations running (to enhance stride length/rate)

- scapula positioned laterally on a mediolaterally flattened thorax (which lengthens stride)
- shoulder joint free to move (becomes effectively a hinge joint stabilized by muscles)
- brachium remains highly muscular & relatively short (keeps limb mass proximal)
- radius becomes the dominant bone in the antebrachium (stability favored over rotation)
- reduction of digits in the manus & pes (stability favored over manipulative dexterity)
- conversion of musculature to ligament (reduced mass & reliance on passive mechanics)
- elongation of the manus/pes (particularly the metacarpus/metatarsus and digits)
- ground contact made with digits (digitigrade) or hoof (unguligrade) (vs plantigrade)

Canine Skeleton



The carnivore requires multipurpose limbs. Four digits are retained, there is still a good size ulna, and manus/pes elongation is moderate

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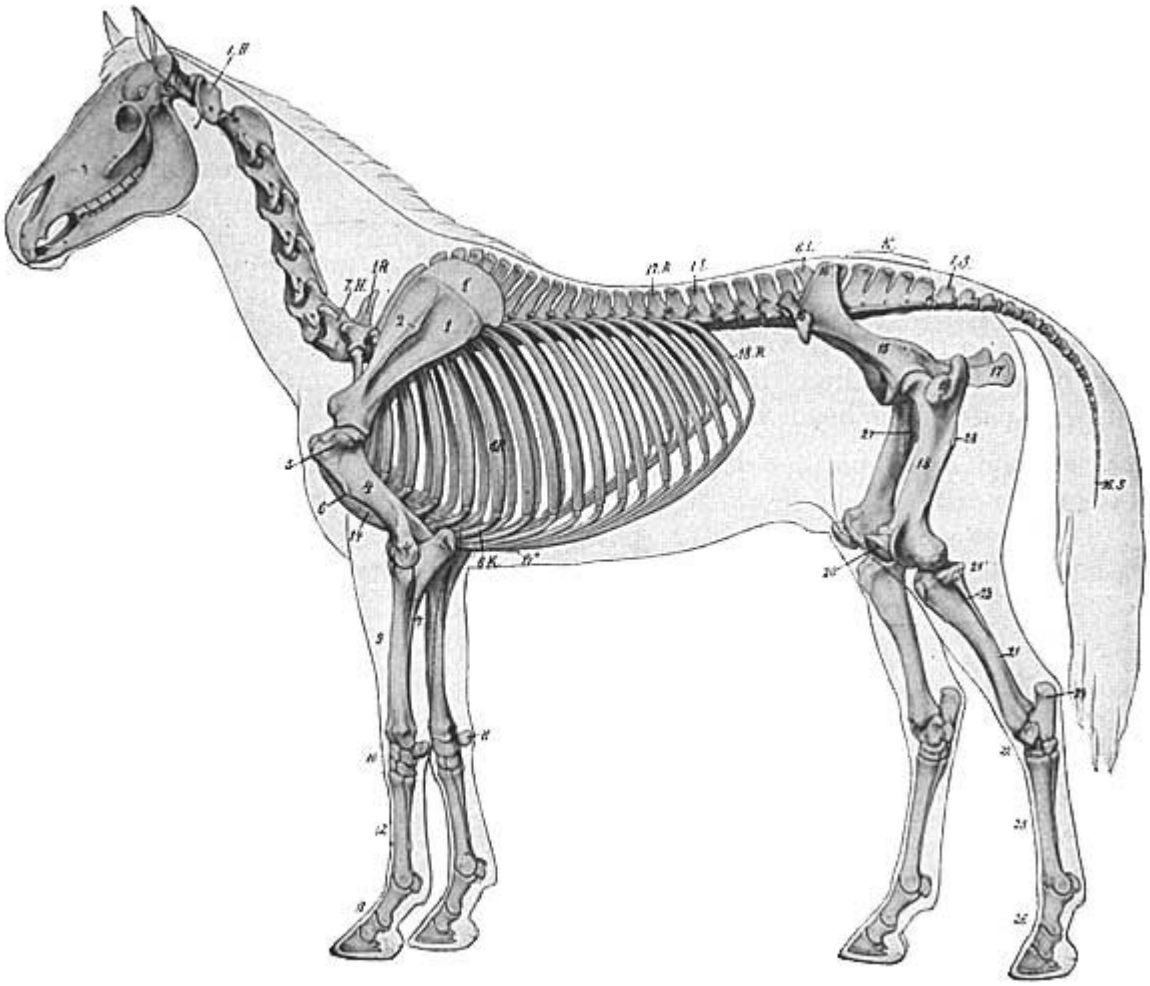
Equine Skeleton



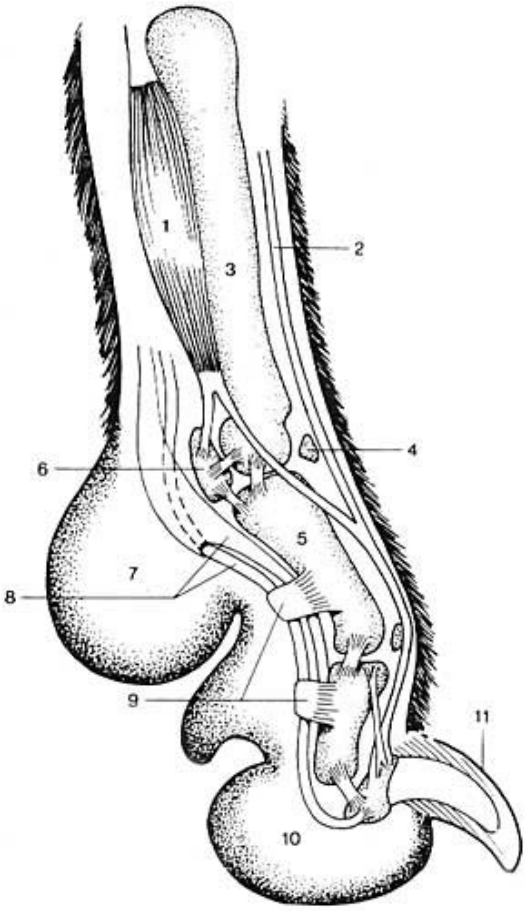
Equine limbs are designed entirely as instruments for running. Only one digit is retained, the ulna is only partially present, and the manus/pes is very elongate.

Note:

The carnivore lifestyle requires limb flexibility and control for grasping and manipulating prey and defending self, offspring, and territory. Thus limb elongation, bone reduction, digit elimination, and conversion of muscle to ligament is moderated. The unguis (nail) in not used for locomotion and remains available as a "tool". To catch long-leg prey, the carnivore must obtain long stride length physiologically, by trunk flexion and extension (which requires much energy expenditure).

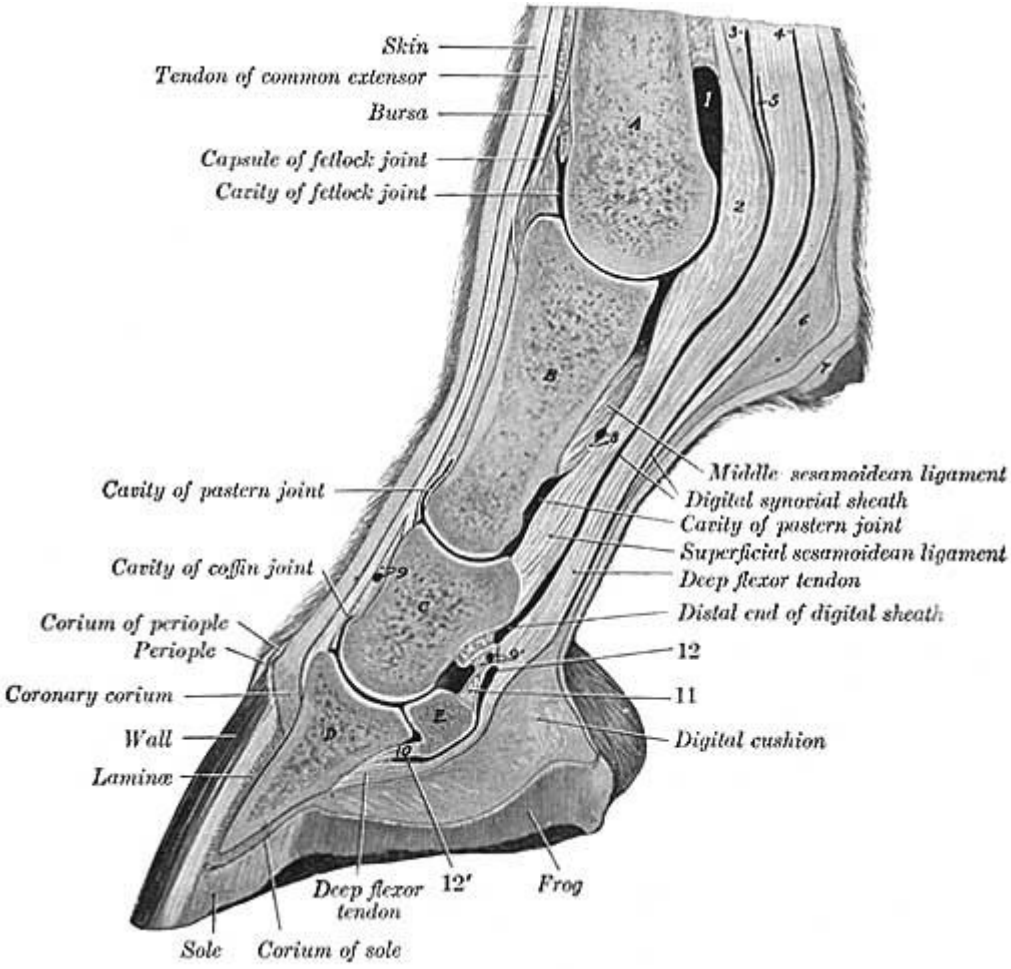
The equine exhibits extreme anatomical specialization for running. It walks on the hoof of a single digit of an elongate manus/pes in which muscle is replaced by ligament. The digestive apparatus of the horse predisposes it to continual grazing (in the wild). Accordingly, the horse has evolved ligament structures that facilitate such a lifestyle, including prolonged standing with minimal expenditure of muscular energy (stay apparatus), mechanical joint linkage (reciprocal apparatus), and mechanical energy conservation through potential/kinetic energy exchange (e.g., fetlock translation).

Canine Metacarpus and Digit



The dog is a digitigrade that walks on four digits (four digital pads). An interosseus muscle supports each fetlock joint. The four fetlock joints press against a single metacarpal pad.

Equine Foot (Bisected)



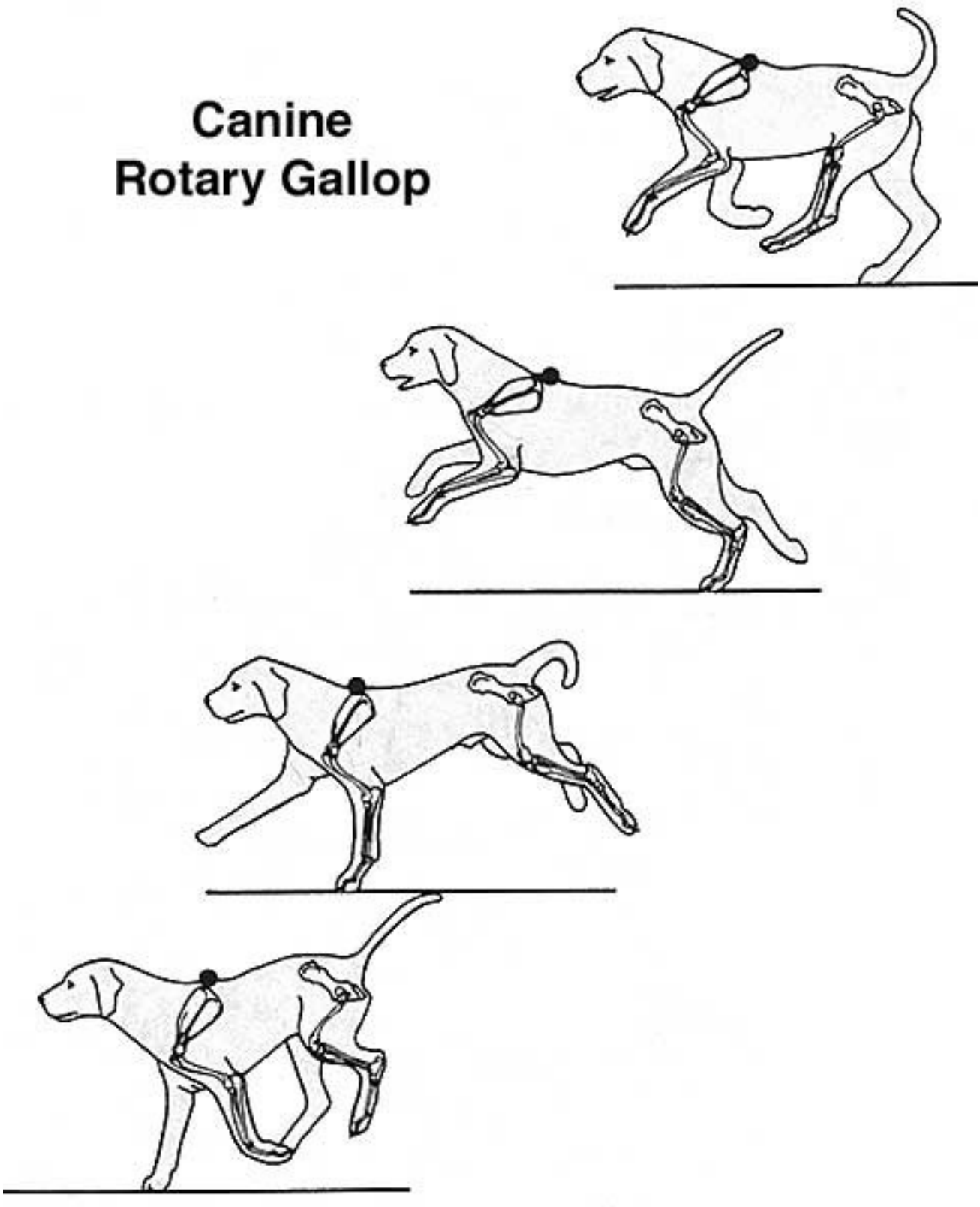
The horse has a single digit. The horse is an ungulate that walks on a hoof within which the distal phalanx is suspended by contact between laminae.

Forelimb vs. Hindlimb Differences

Forelimbs and hindlimbs have different roles in cursorial quadrupeds. Consequently they are anatomically different:

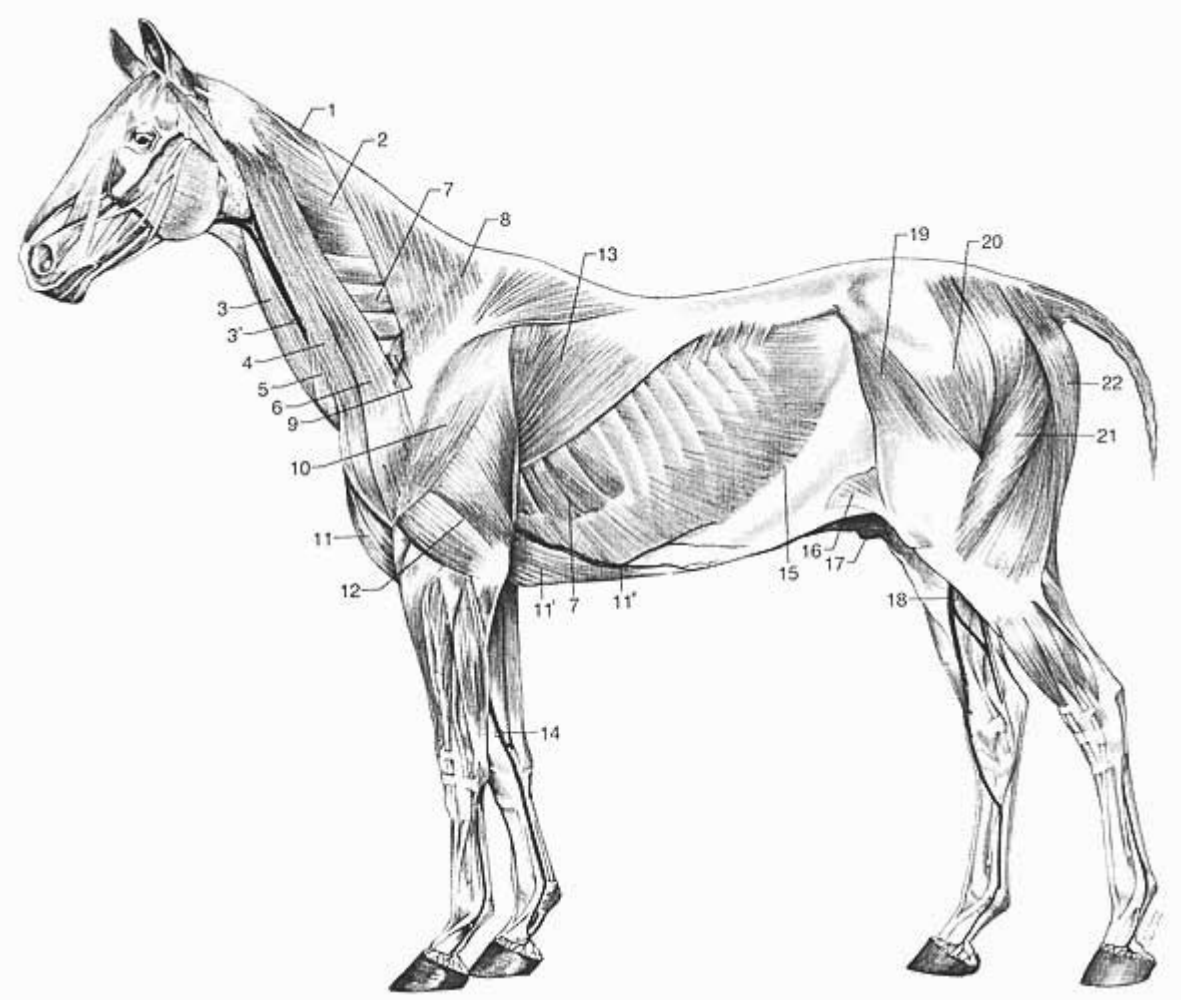
Forelimbs (thoracic limbs) carry 60% of static body weight. They are designed to catch body weight as it is thrown forward by pelvic limbs. Forelimbs improve gait efficiency by minimizing wasteful up/down energy expenditure (they absorb kinetic energy of downward movement , store it as potential energy in stretched ligaments, and in turn convert that to upward kinetic energy). Anatomical features of the forelimb include:

- shorter and straighter than the pelvic limb
- connected to the trunk only by muscle and ligament (not bone to bone articulation)
- broader, more rounded hoof (horse)



The forelimb is designed to convert the kinectic energy of impact into the potential energy of stretched ligaments, which are capable of rebounding to generate kinetic energy for upward movement.

Equine Thoracic and Pelvic Limbs



The thoracic limb is straighter and designed for carrying weight and absorbing impact force. The pelvic limb is more angular. It is designed for propulsion.

Hindlimbs (pelvic limbs) are the "motors" of locomotion. They drive the trunk forward and propel the body up/over obstacles during jumps. Anatomical features of the hindlimb include:

- longer and more angular than the thoracic limb
- osseous articulation to the trunk (axial skeleton) through a sacroiliac joint
- musculature capable of simultaneously extending hip, stifle, and hock
- narrower, more pointed hoof (horse)

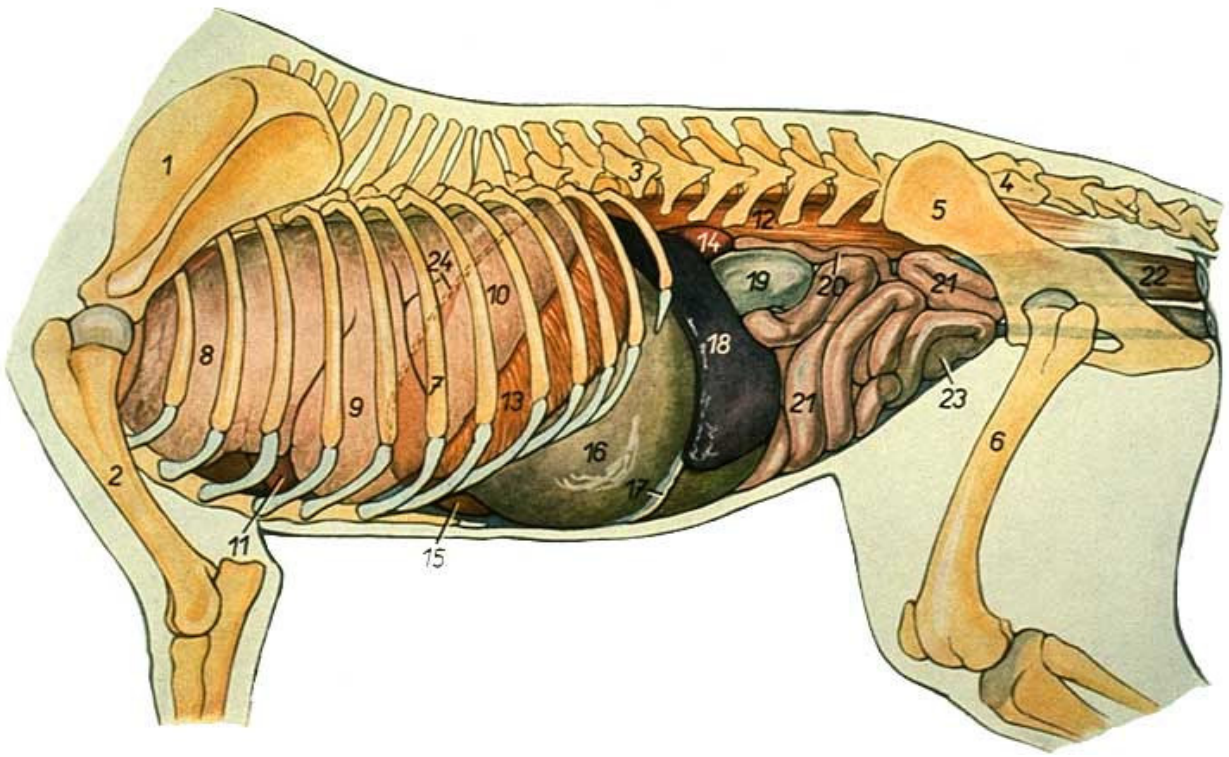
Carnivore vs. Herbivore Digestive Tracts

The different diets of domestic mammals have associated anatomical, physiological, and behavioral implications. Locomotor anatomy and behavior are linked to diet, the nature of the digestive tract in the abdomen has implications for locomotion. Features of three types of digestive tracts are:

Canine digestive tract

- simple glandular stomach
- small cecum and simple colon
- small abdominal volume especially when fasted
- high protein diet

Canine Trunk

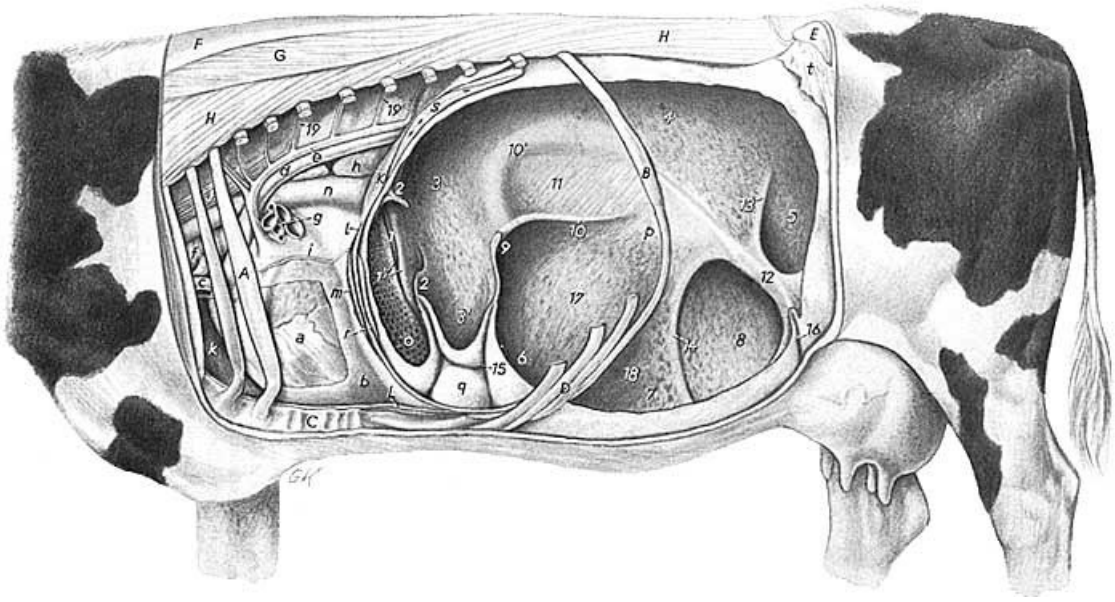


The canine abdomen has a relatively small amount of abdominal viscera, which facilitates trunk flexion and extension during locomotion.

Ruminant digestive tract (cattle, sheep, goat, deer, etc.)

- huge stomach with four compartments (fermentation chambers and a glandular compartment)
- large cecum and coiled ascending colon
- large abdominal volume even if fasted
- rumen flora and fermentation products supplement a roughage diet

Bovine Trunk

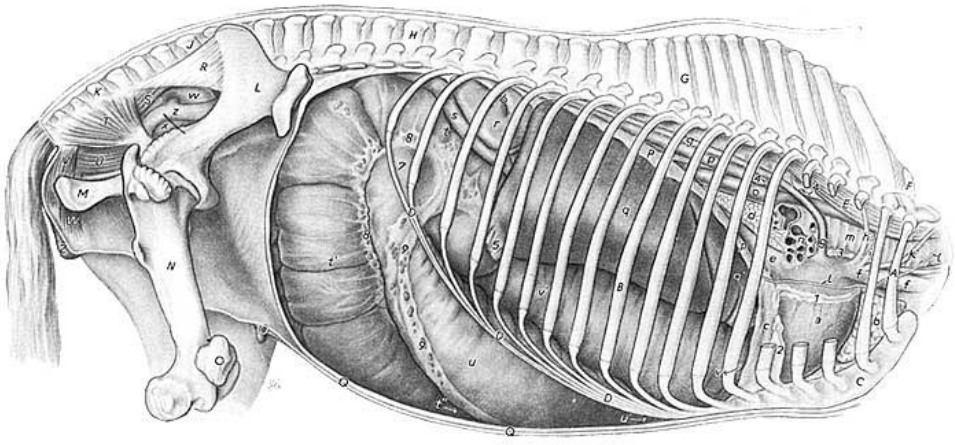


The bovine abdomen is filled with a huge ruminant stomach, which impedes trunk flexion and extension during locomotion.

Equine digestive tract

- simple stomach (half glandular)
- huge cecum and ascending colon
- large abdominal volume even if fasted
- roughage diet requires a protein source (obtained via grain or coprophagy)

Equine Trunk



The equine abdomen contains a very large cecum and colon. The massive viscera impede trunk flexion and extension during locomotion.