Cardiovascular and Respiratory Function in Horses:

Their Role in Determining Racing Performance and How Training Affects Them

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Topics

- Comparative exercise physiology
- Energy use during exercise – muscles
- Sources of energy during exercise
- Importance of oxygen for supplying energy in racing
- Roles of heart and lungs in delivering oxygen to muscles
- How training affects heart and lungs
- Related issues – bleeding, shipping fever
- Questions

Comparative Exercise Physiology

Study different animals when they exercise in order to better understand factors that affect and limit the exercise capacity and racing ability of the horse

Giannini Equine Athletic Performance Lab

Exercise measurements in lab with controlled conditions

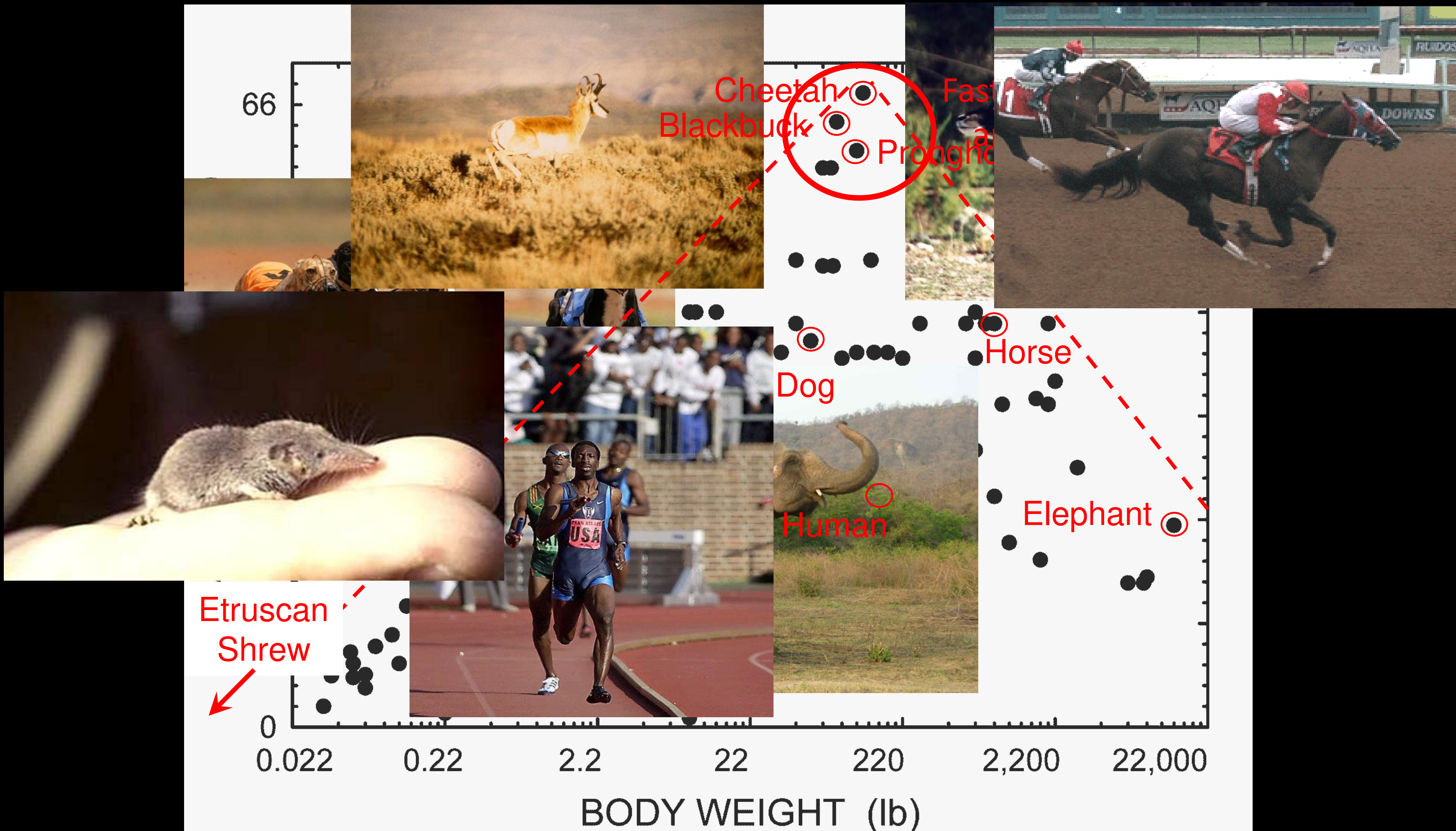
Japanese *Ban-ei*（輓曳)

Hokkaido Draft horse races – 1000 lb sled with hills

Jockey only uses reins, no whip - 200 yd in 4 minutes

Maximum running speeds of mammals

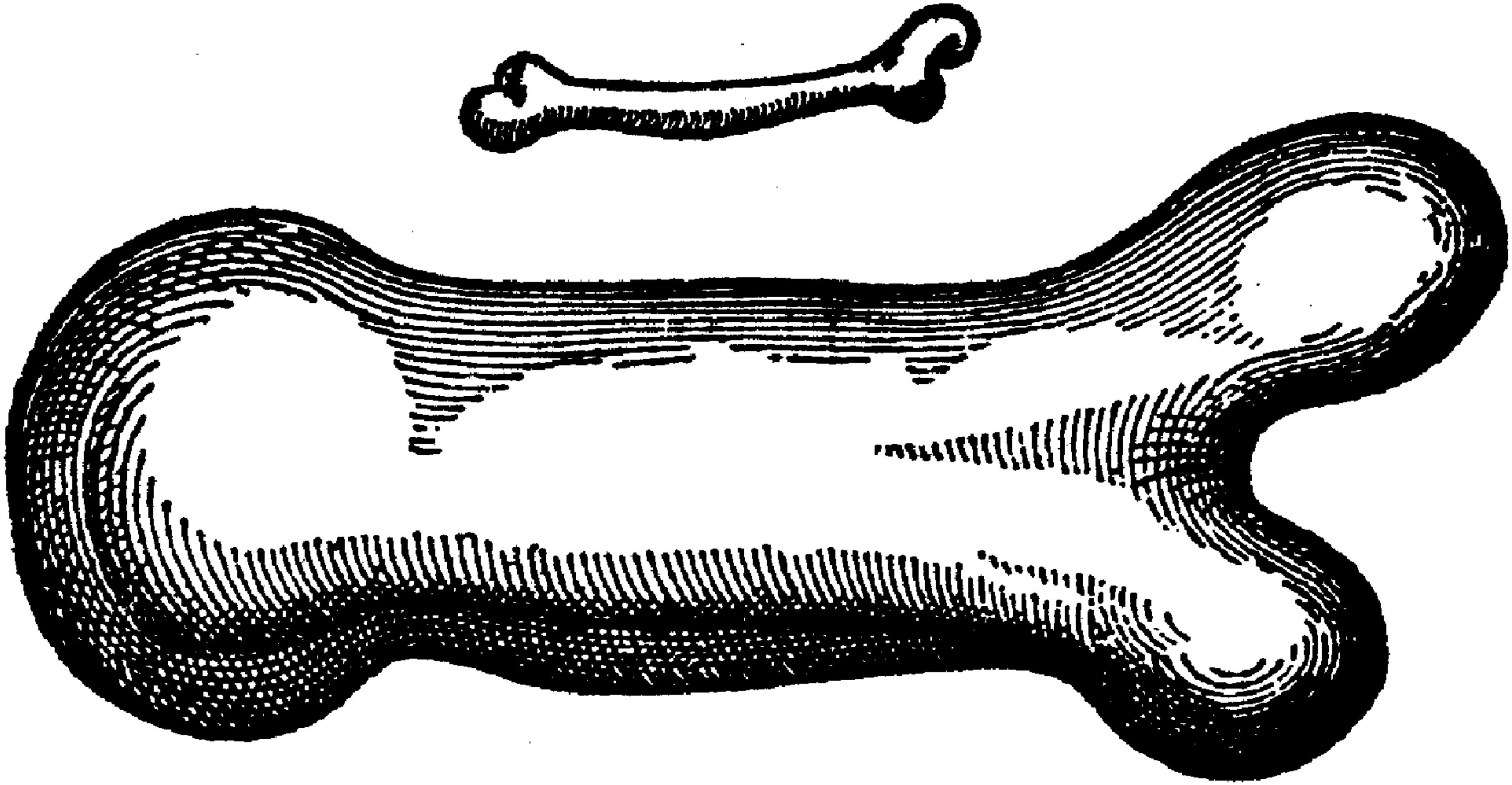
(J.H. Jones and S.L. Lindstedt (1993) *Ann. Rev. Physiol. 55*)



Limb Excursions during Running and Body Size

¼ oz Pygmy Mouse

12,000 lb African Elephant



Galileo Galilei (1637)

Discorsi e dimostrazioni matematiche, intorno à due nuove scienze racing starts results in a

culoskeletal injury

ess Stakes 2006

Barbaro

2006 Kentucky Derby

110 lb Pronghorn Antelope Cannon Bone

Pronghorn Antelope and Cheetah
Fastest Mammals – 100 lb

Pronghorn Antelope Fawn

What physiologically determines a horse’s racing performance?

The horse that applies the greatest amount of *mechanical power* to the ground in a *coordinated* manner will propel itself the fastest around the track

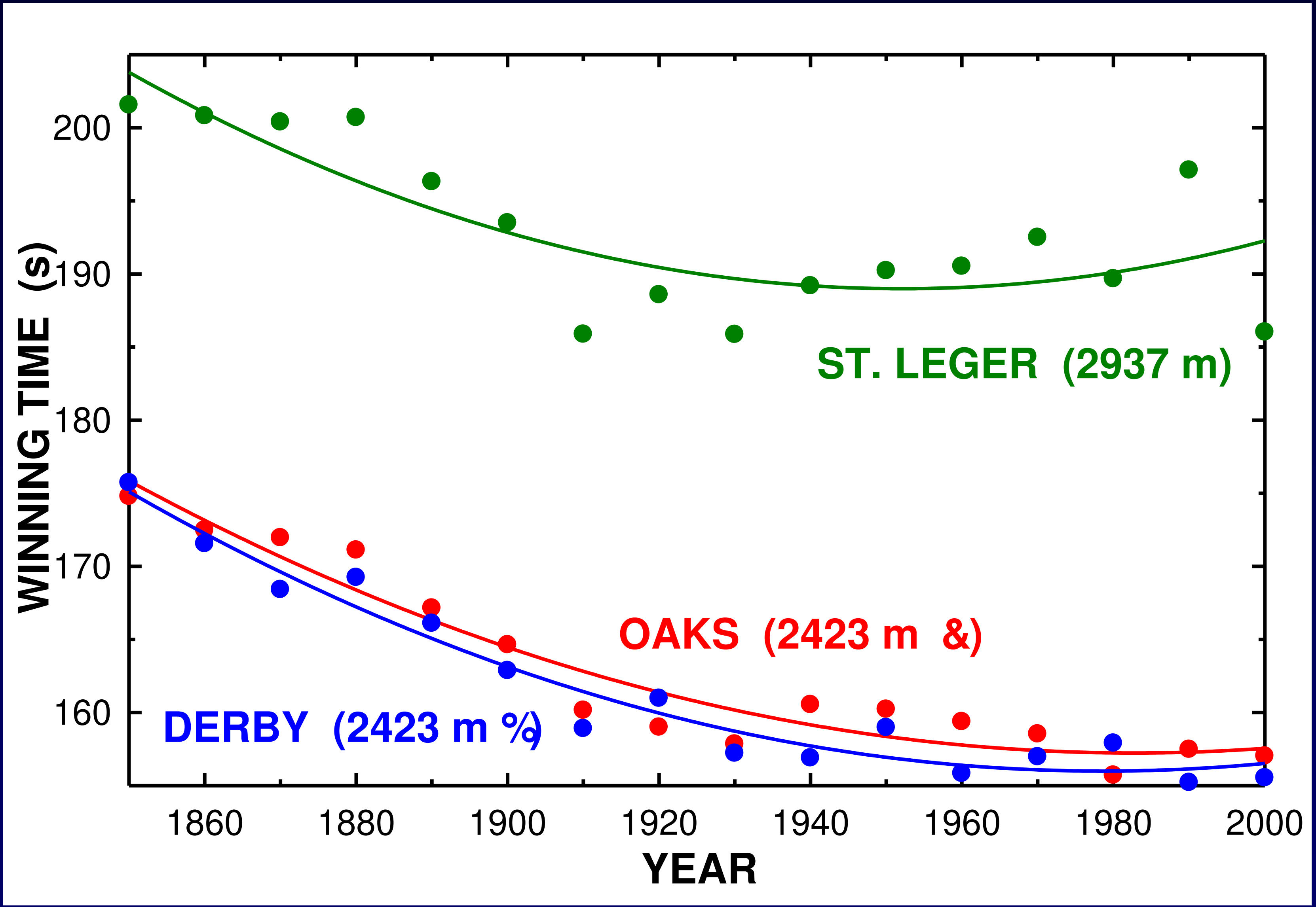
What physiologically determines a horse’s racing performance?

- *Coordination* is determined by conformation and the development of nervous system control of movement and stride = efficient gait

- *Mechanical power* is determined by the amount of force developed by the muscles and their speed of shortening – and *how long* peak power can be maintained – this is affected by *training*

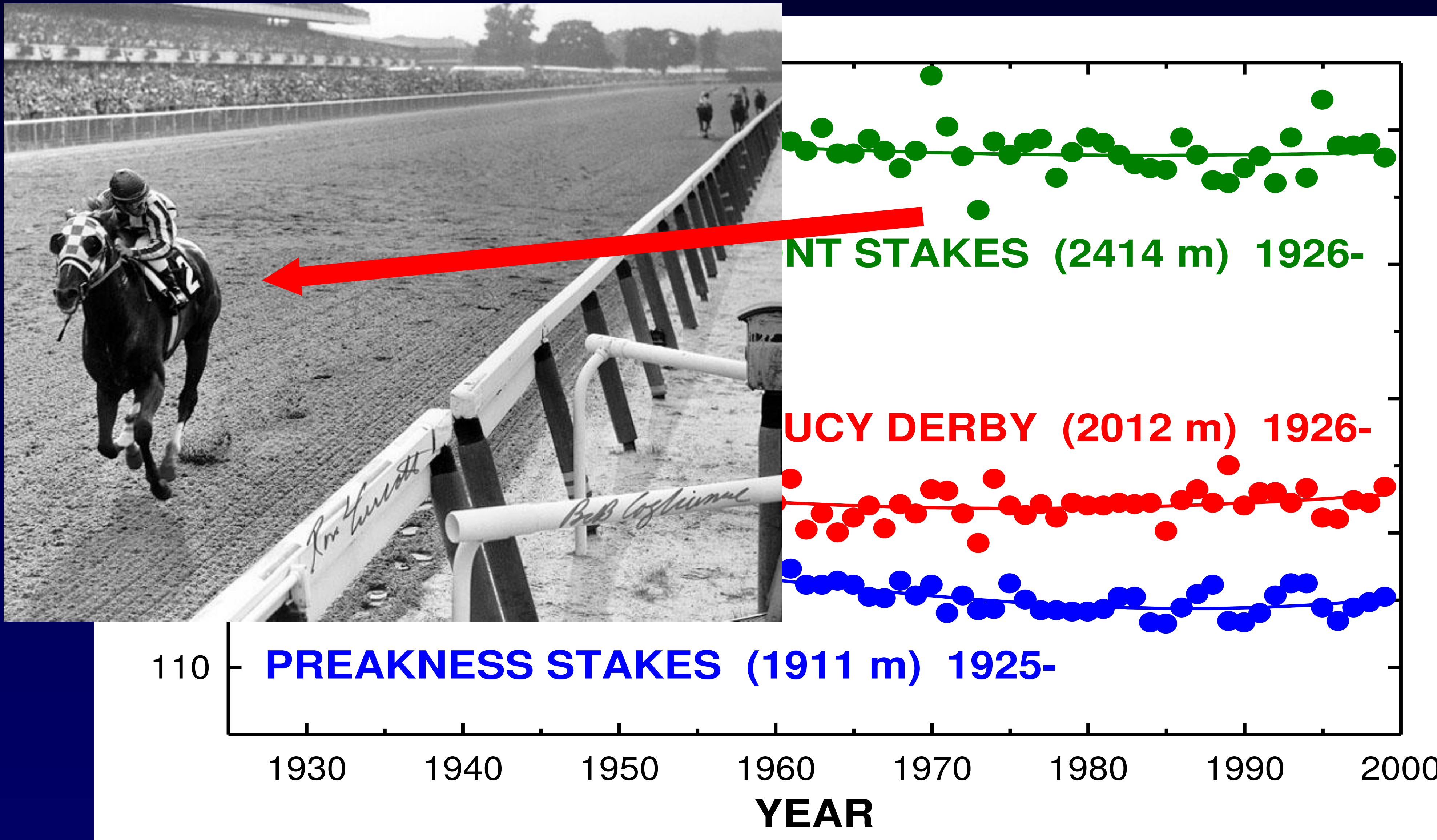
British Triple Crown races winning times, decade averages, 1845-1999

J.H. Jones (1998) *Principles of Animal Design*, E.R. Weibel *et al.* (*eds.*)



American Triple Crown races annual winning times, 1925/26-1999

J.H. Jones (1998) *Principles of Animal Design*, E.R. Weibel *et al.* (*eds.*)



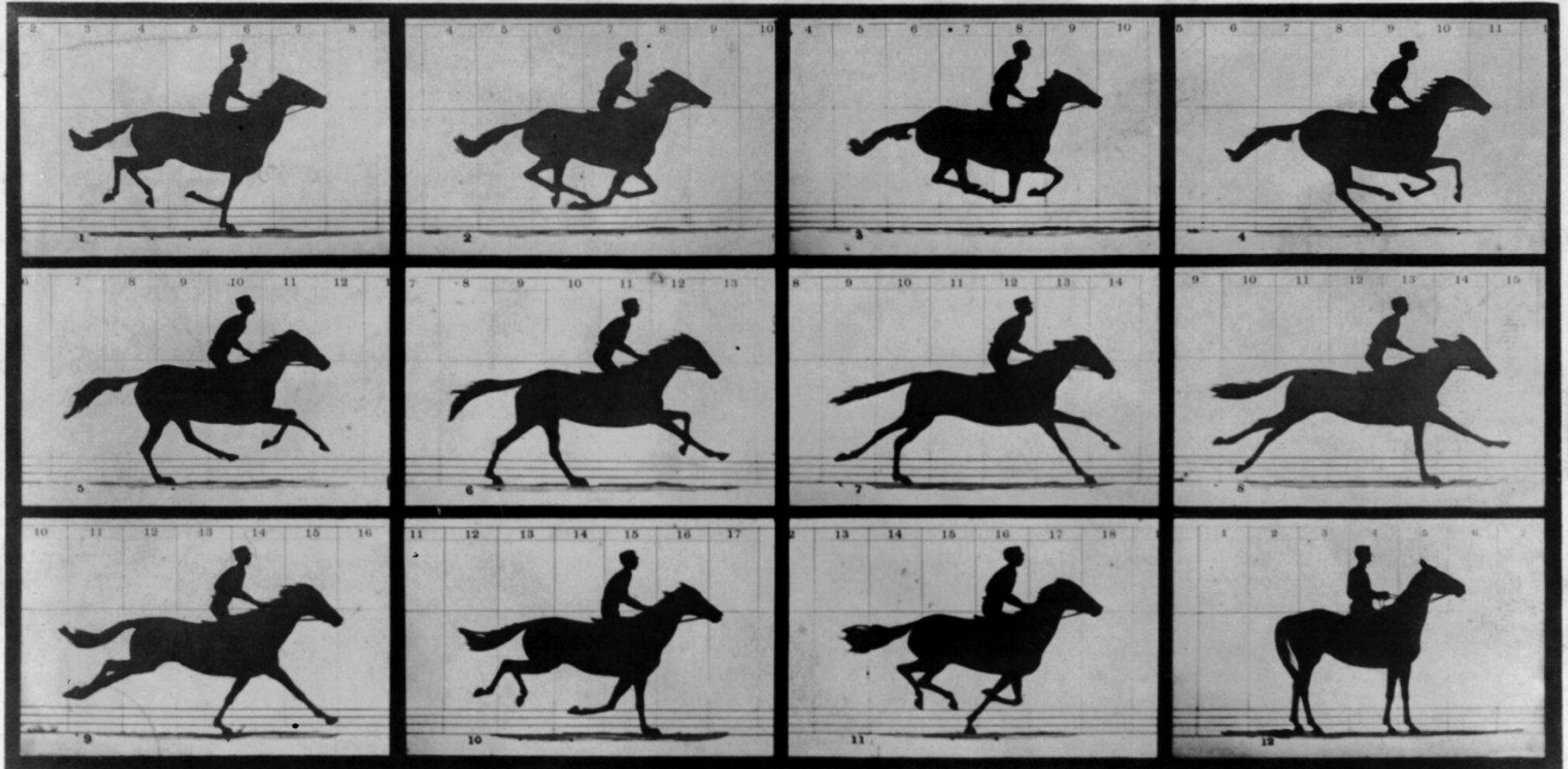
What is the majority of energy used to do during locomotion, *i.e.*, what is the major *energy cost* of locomotion?

Most of the energy used during locomotion is used to support the animal's body weight *vs.* gravity!

Why does it cost more energy to move faster than slower?

Whether an animal moves quickly or slowly, most of the energy used by its muscles is simply being used to support its body weight against gravity – *but the amount of force and rate of its application change with speed*

Force-integrated Treadmill
Dr. M. Weishaupt – Univ. Zurich



MORSE'S Gallery, 417 Montgomery St., San Francisco.

THE HORSE IN MOTION.

Illustrated by

MUYBRIDGE.

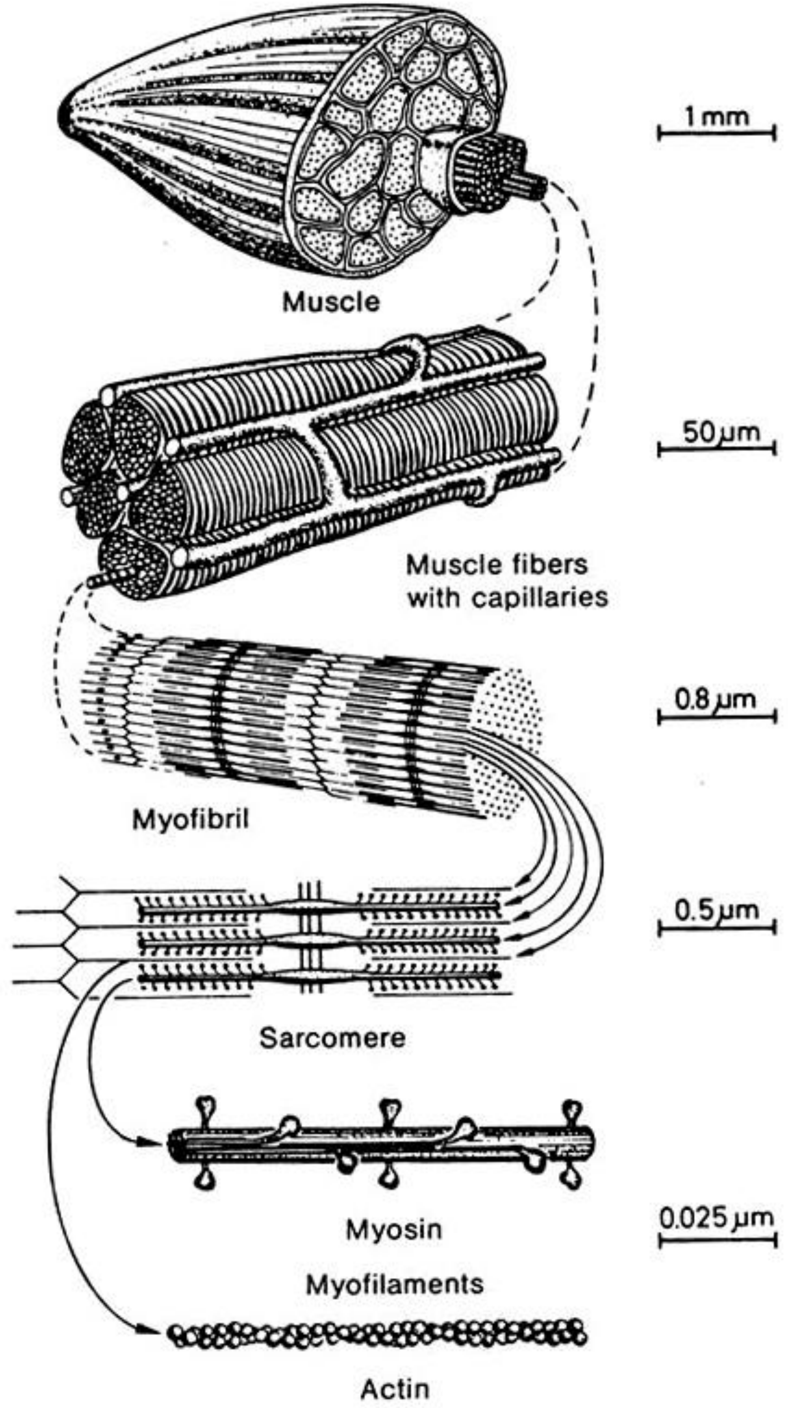
AUTOMATIC ELECTRO-PHOTOGRAPH.

"SALLIE GARDNER," owned by LELAND STANFORD; running at a 1.40 gait over the Palo Alto track, 19th June, 1878.

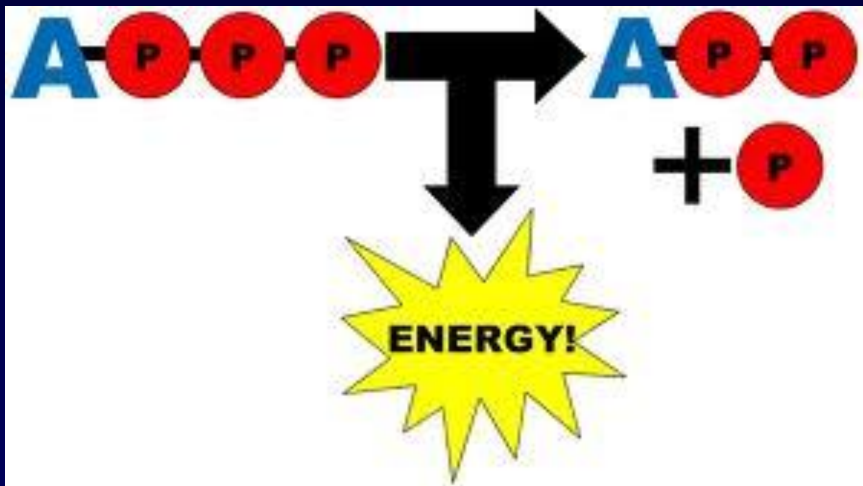
The negatives of these photographs were made at intervals of twenty-seven inches of distance, and about the twenty-fifth part of a second of time; they illustrate consecutive positions assumed in each twenty-seven inches of progress during a single stride of the mare. The vertical lines were twenty-seven inches apart; the horizontal lines represent elevations of four inches each. The exposure of each negative was less than the two-thousandth part of a second.

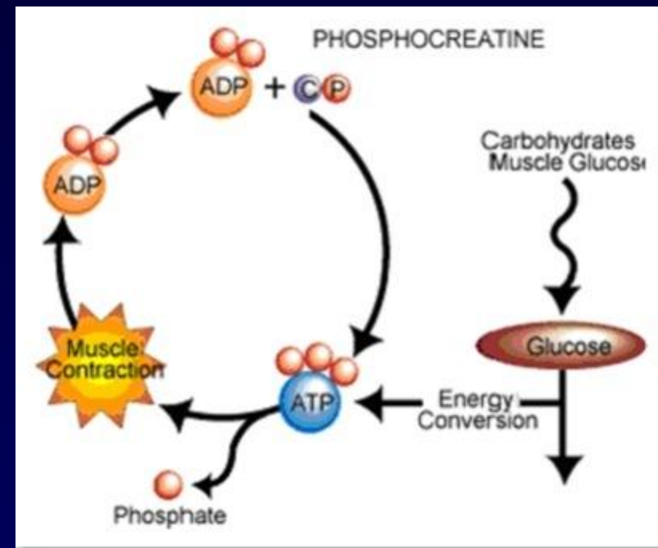
Increased Muscle Force for Higher Speed

- Force is generated when actin and myosin proteins in muscles form temporary cross-bridges
- Each cross-bridge requires the energy contained in a chemical called ATP to generate force
- More force requires use of a greater amount of muscle that is faster and uses more ATP to generate the same amount of force over time



Breakdown of ATP to ADP releases energy to muscle

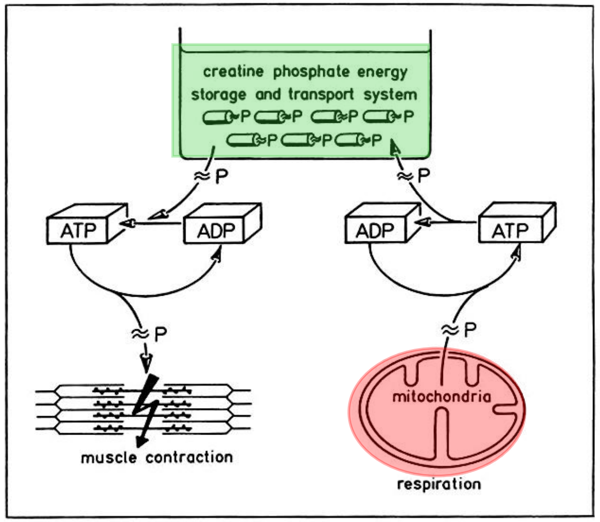


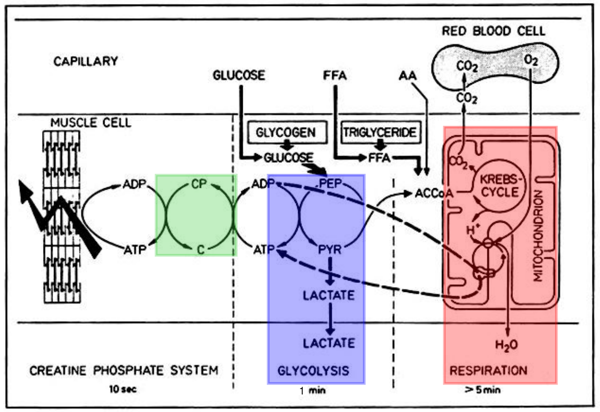


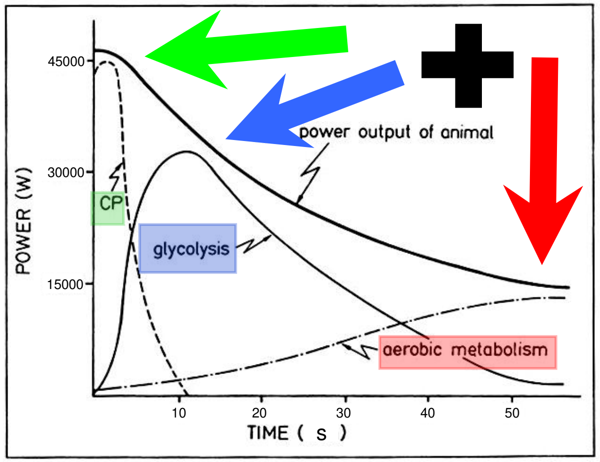
ADP requires energy from muscle metabolism (aerobic or anaerobic) to restore ATP

Duration of Peak Metabolic Power

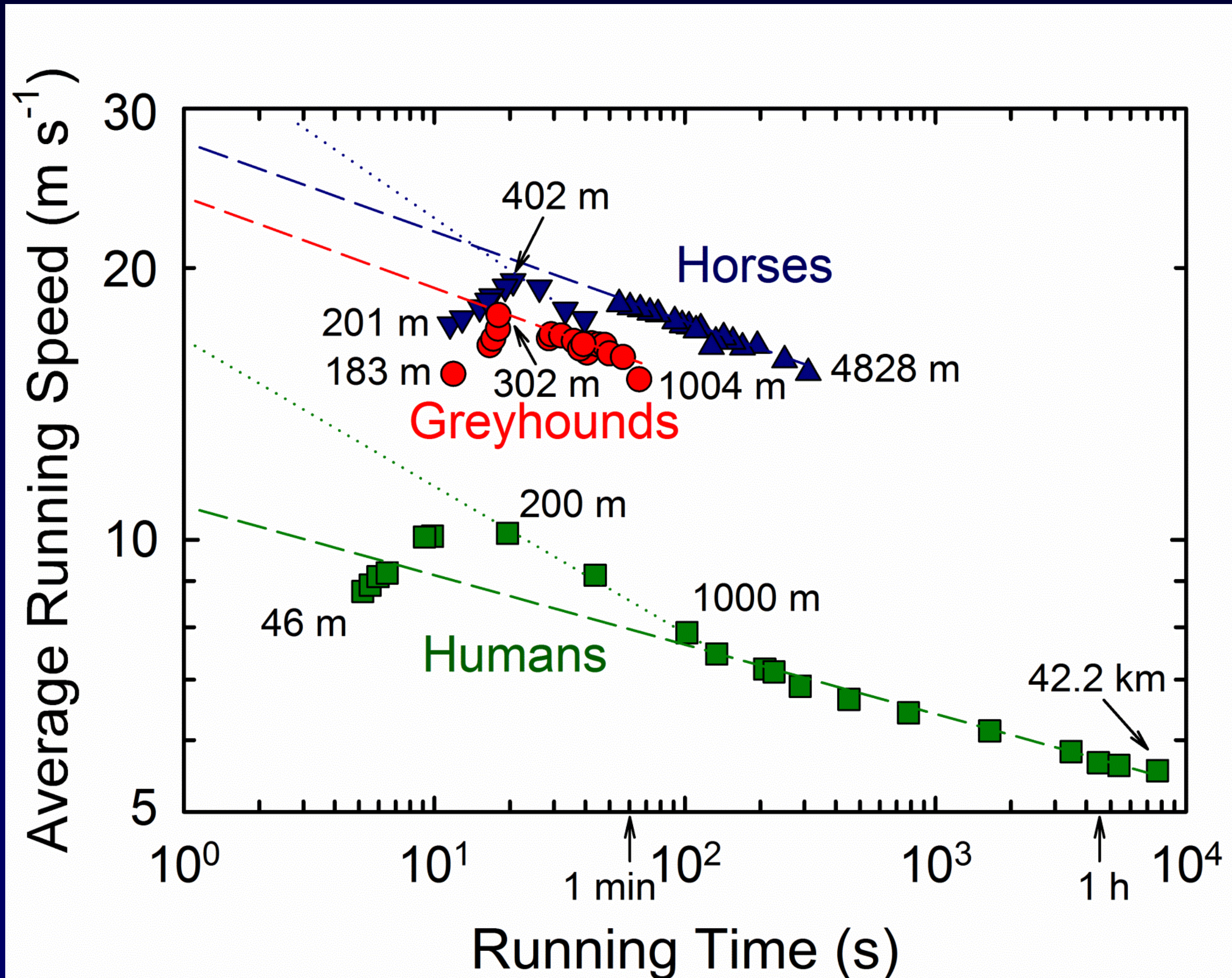
- For muscle to continue to generate force for more than a few seconds, ATP must be replenished by adding a ~P to ADP from creatine phosphate (CP), anaerobic glycolysis or aerobic (using oxygen) ATP resynthesis
- Highest total metabolic power occurs for the shortest possible duration – single contraction
- Sprint races occur with significant ATP from anaerobic glycolysis and ↑ Lactic Acid (LA)
- Longer duration exercise can only be sustained with aerobic = slower speed
- Sprint at end increases anaerobic glycolysis above aerobic limit (VO_2max) = ↑ Lactic Acid



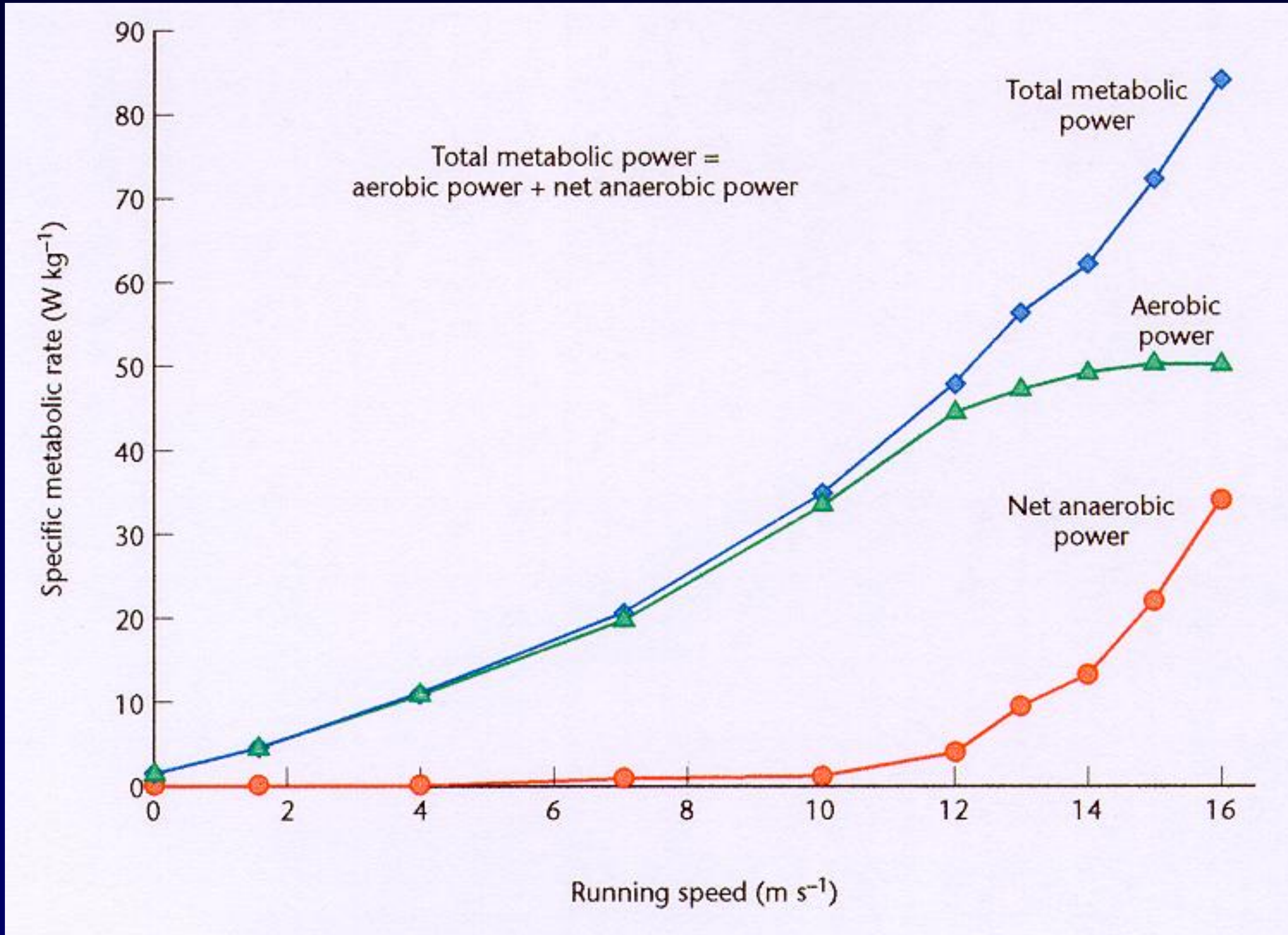




World Record Running Speeds



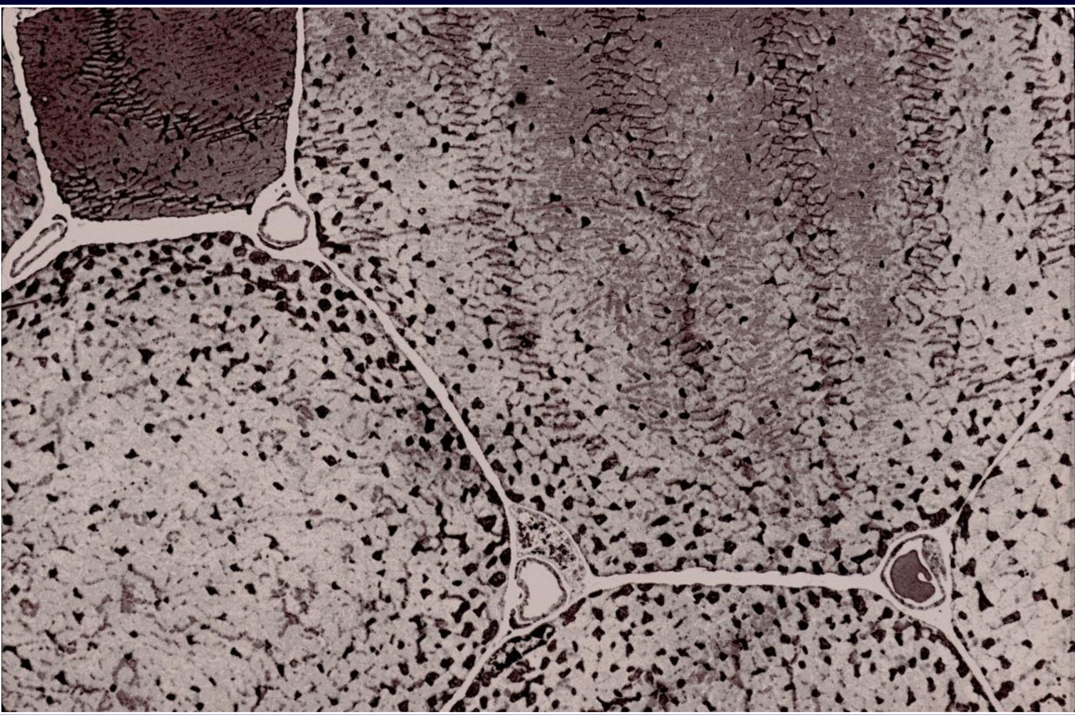
↑ Speed Requires ↑ Total Metabolic Power

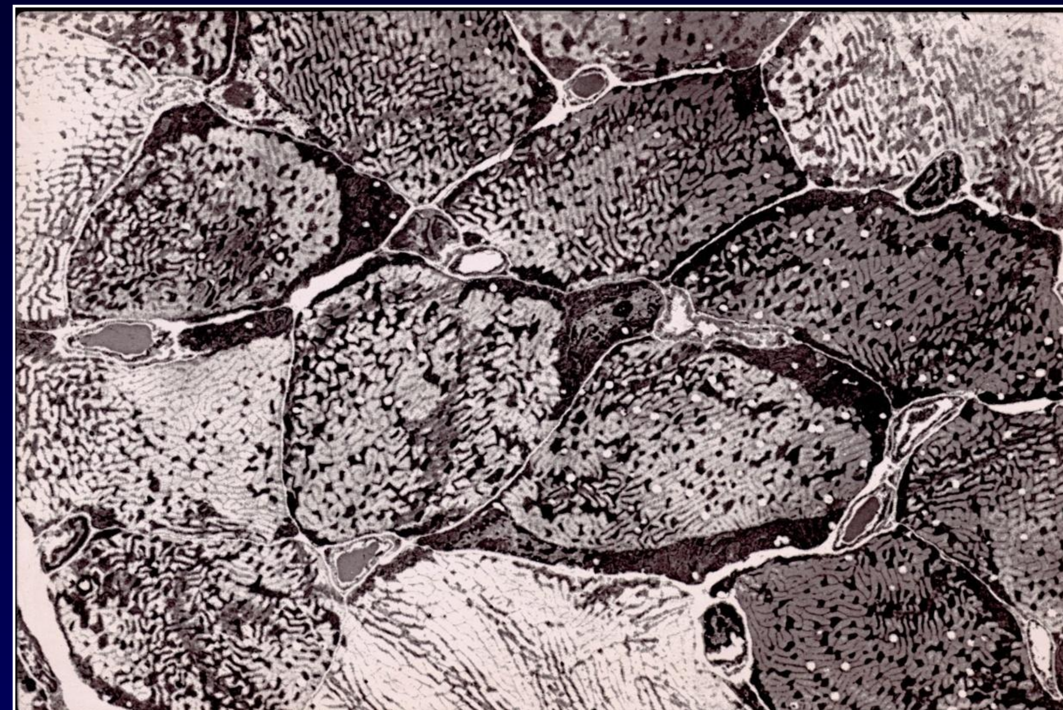


Strength

Endurance

Skeletal Muscle Plasticity





Strength-trained fibers:

- large diameter
- low capillary:fiber ratio
- uses little oxygen
- fast shorten,

[glycogen]

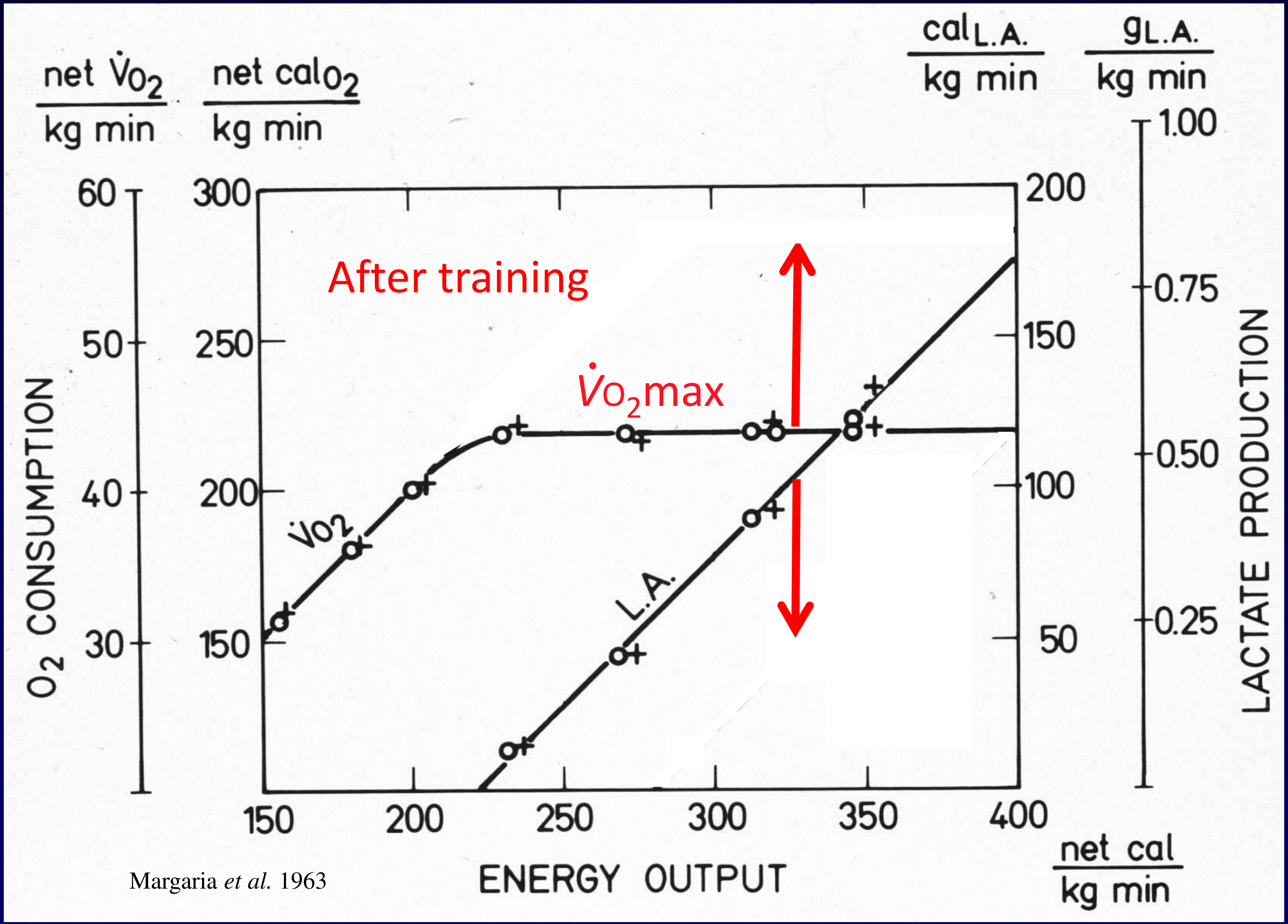
Endurance-trained fibers:

- small diameter
- hi capillary:fiber ratio
- uses much oxygen
- slow shorten,

[glycogen]

↑ Speed Requires ↑ Total Metabolic Power

Training Effects on Aerobic Capacity and Lactic Acid



The Respiratory System

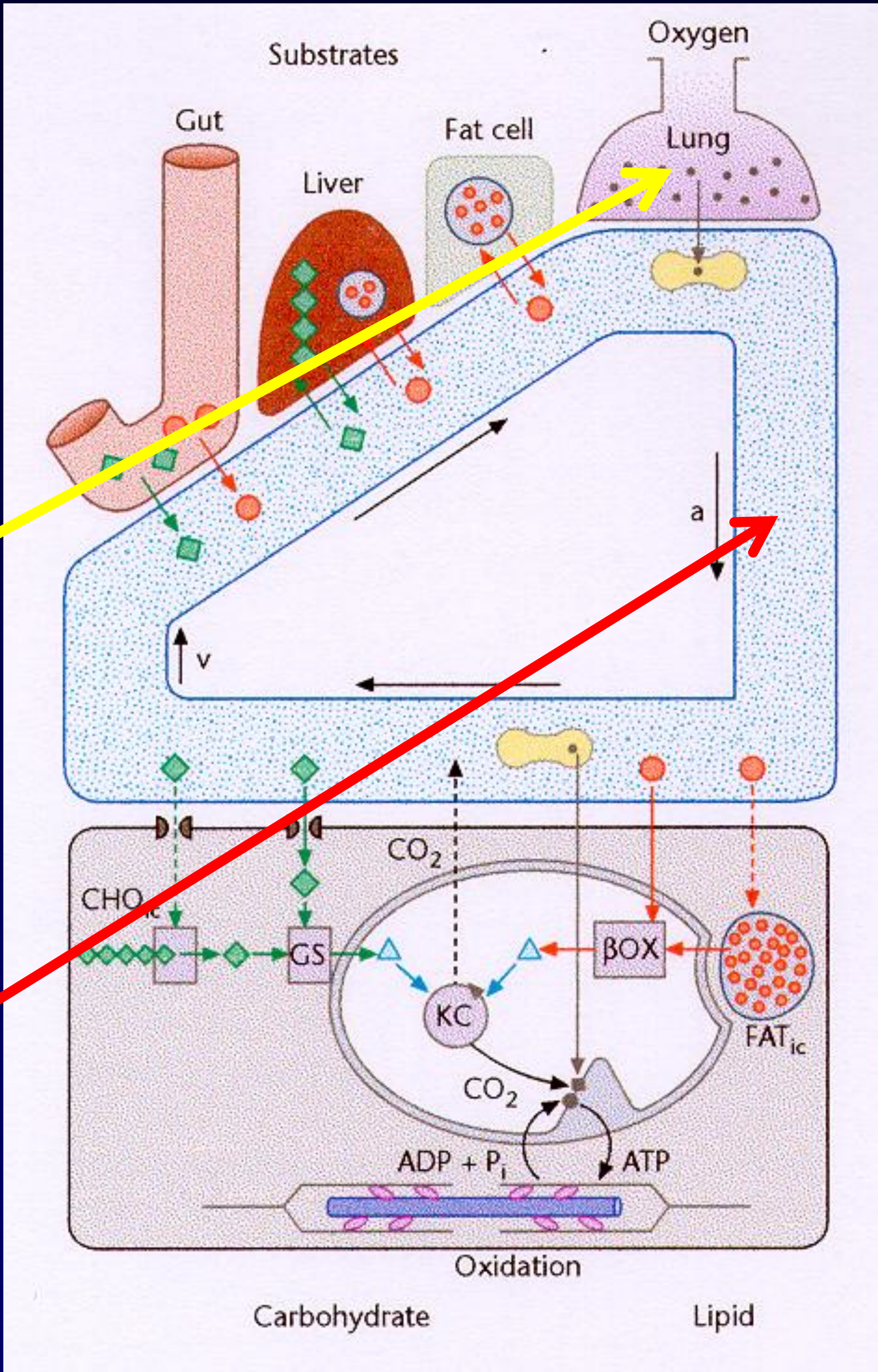
It’s bigger than you think!

Lungs – bring oxygen into the body, remove carbon dioxide – an acid!

$$\frac{breaths}{minute} \times \frac{volume}{breath} = \frac{volume}{minute}$$

Heart – pumps blood carrying oxygen to the muscles, carries carbon dioxide to lungs for removal from body

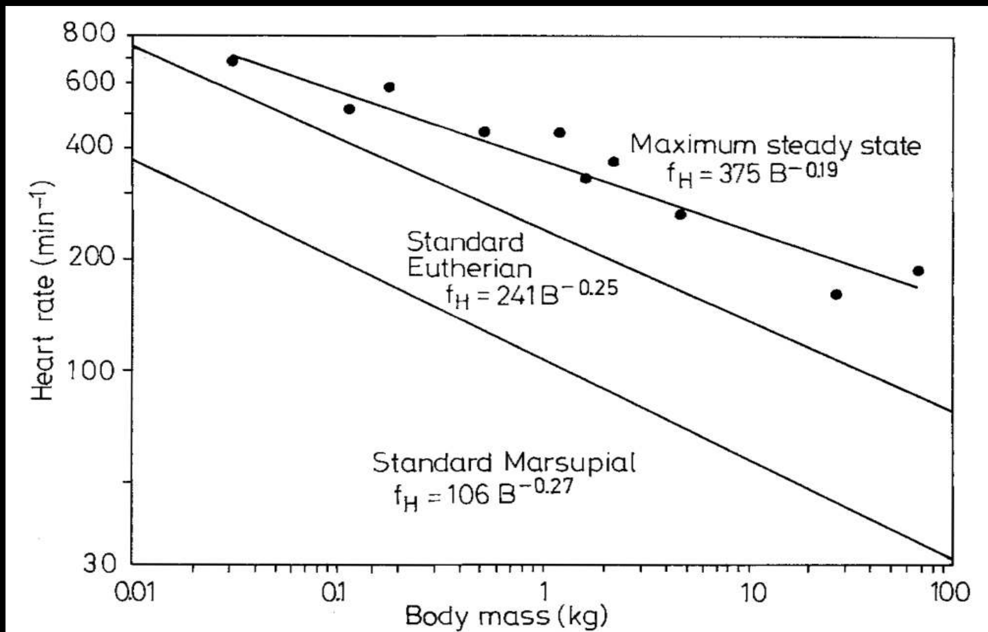
$$\frac{beats}{minute} \times \frac{volume}{beat} = \frac{volume}{minute}$$

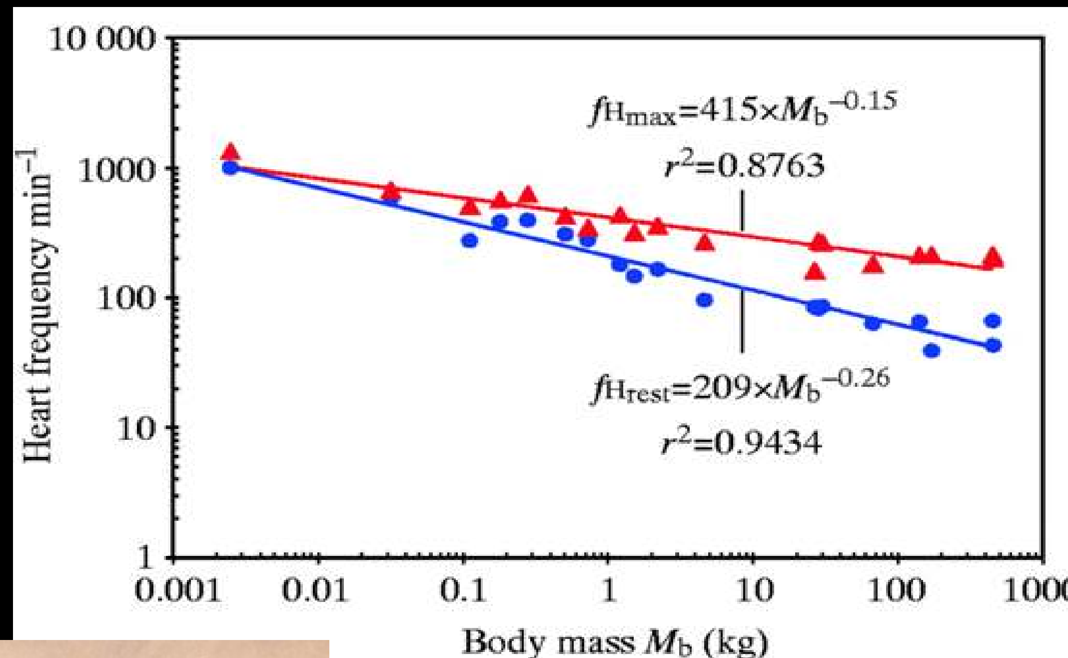


Maximal Heart Rates of Mammals (Allometric)

R.V. Baudinette (1978)
J. Comp. Physiol. 127

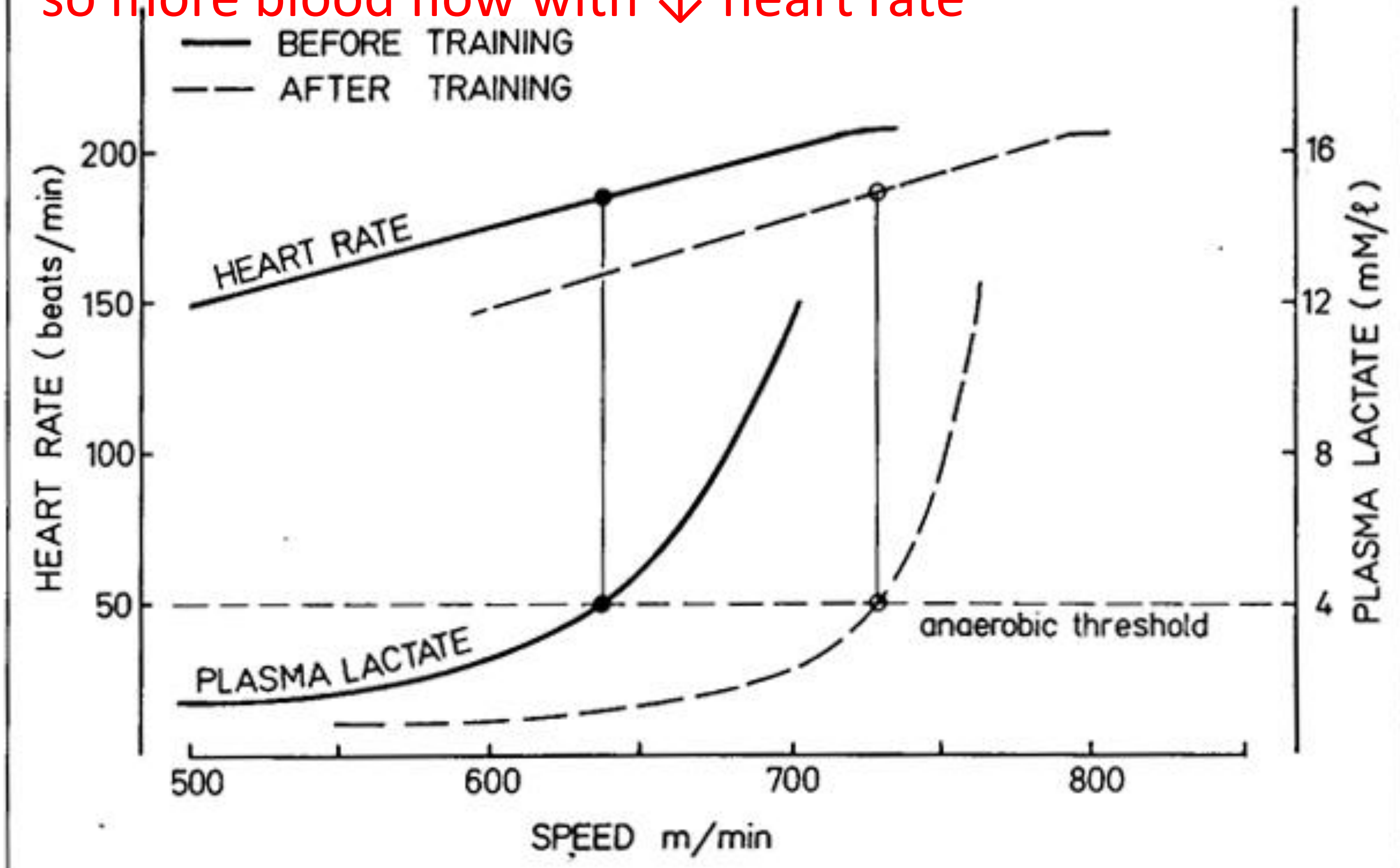
Weibel, E.R. *et al.* (2005)
J. Exp. Biol. 208





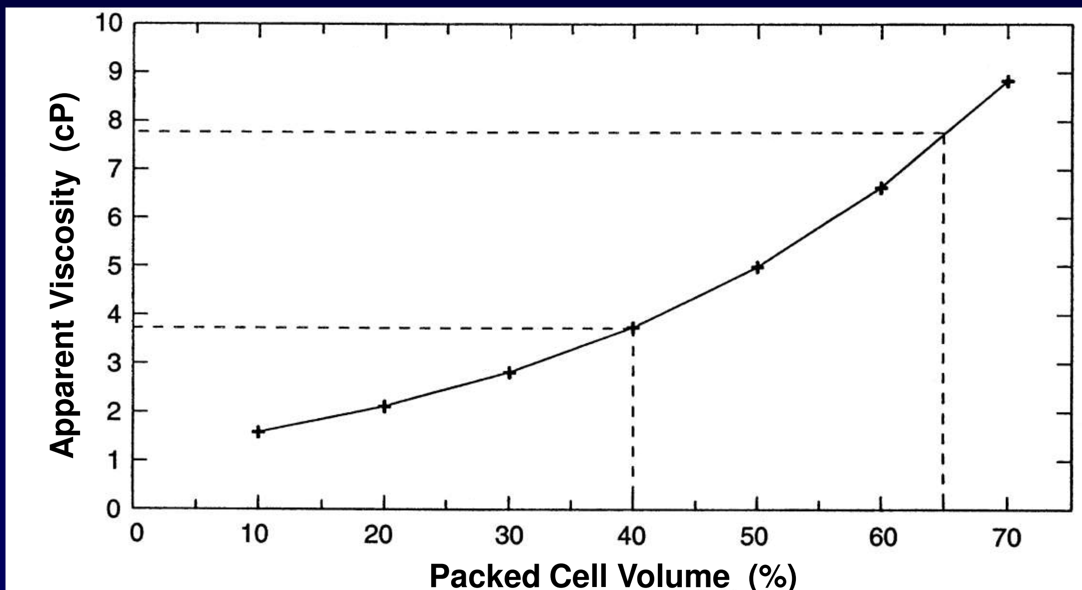
Training Effects on Heart Rate and Lactate

Heart is a muscle and gets stronger and larger with use (training) – volume of blood with each stroke ↑, so more blood flow with ↓ heart rate



Hematocrit and blood viscosity changes in exercising Thoroughbreds (shear rate 450/s)

M.R. Fedde and H.H. Erickson (1998) *Eq. Vet. J. 30*



5% 50% 100%

Percent $\dot{V}O_2$max

Visceral Piston Linking Stride and Breathing

D.M. Bramble and D.R. Carrier (1983) *Science 219*: 251-256

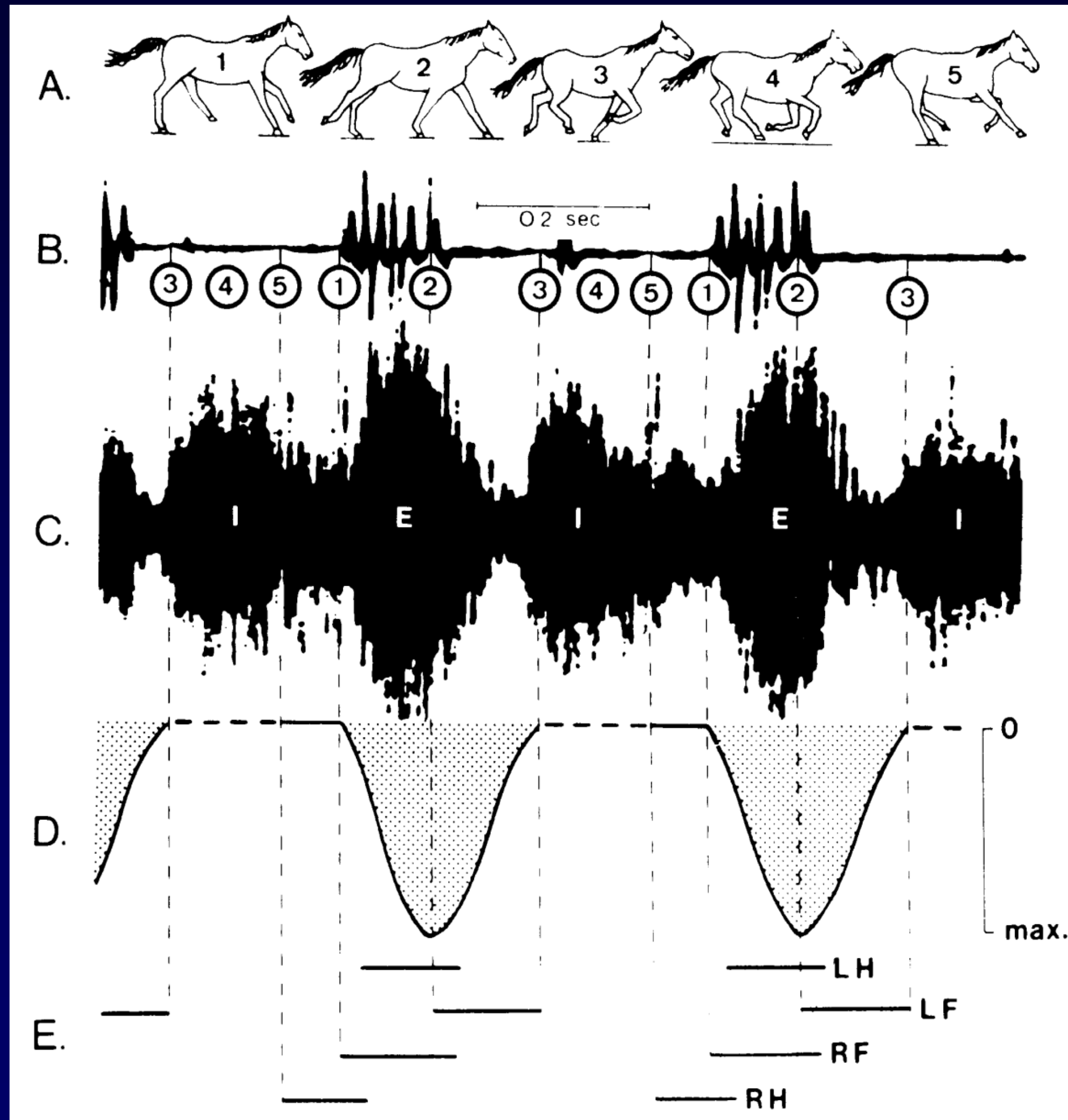
Body position

Footfall

Ventilation

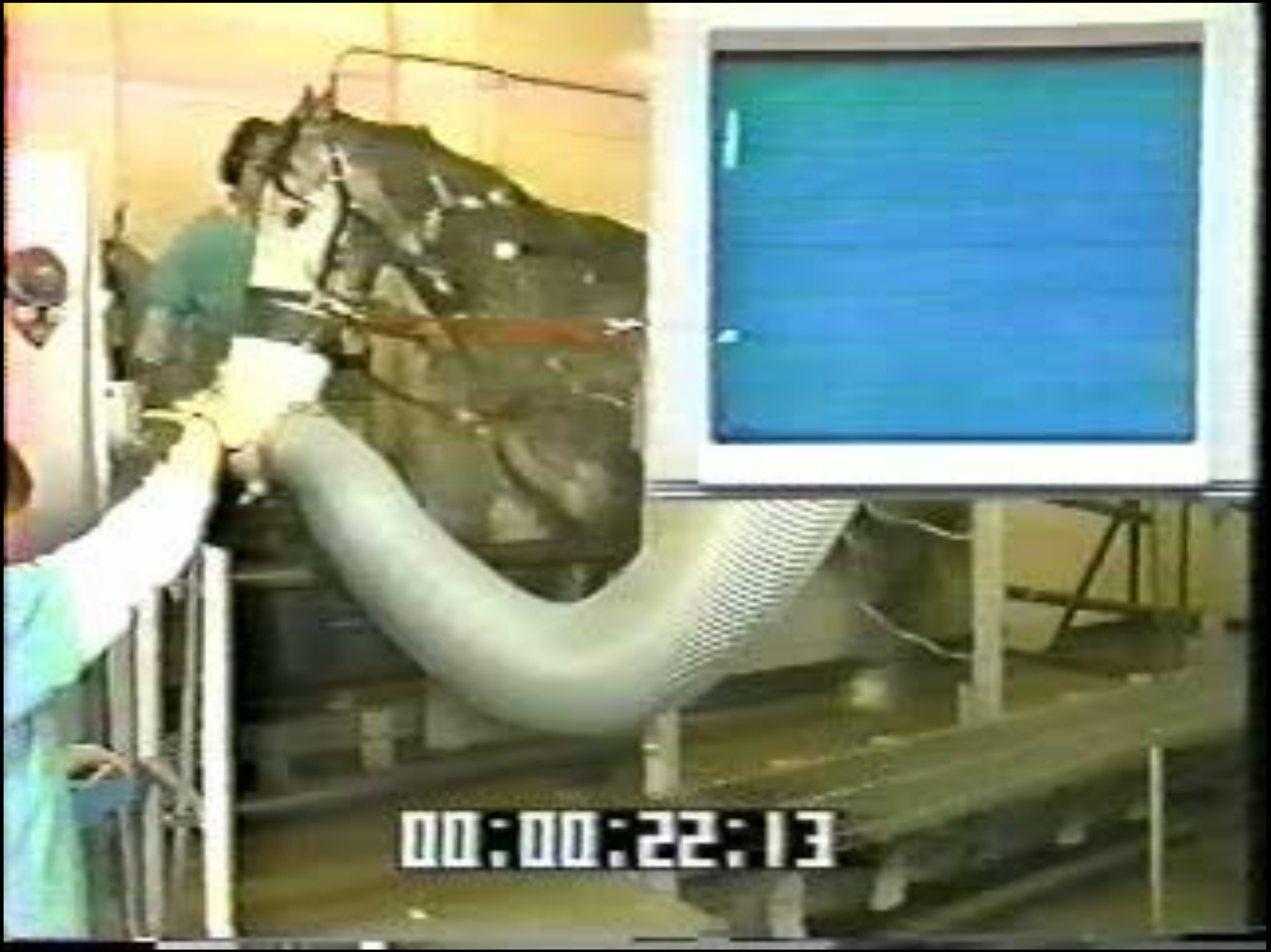
Thoracic loading

Support



Mammalian lung volume *vs.* Body mass

Breathing entrainment with stride during gallop



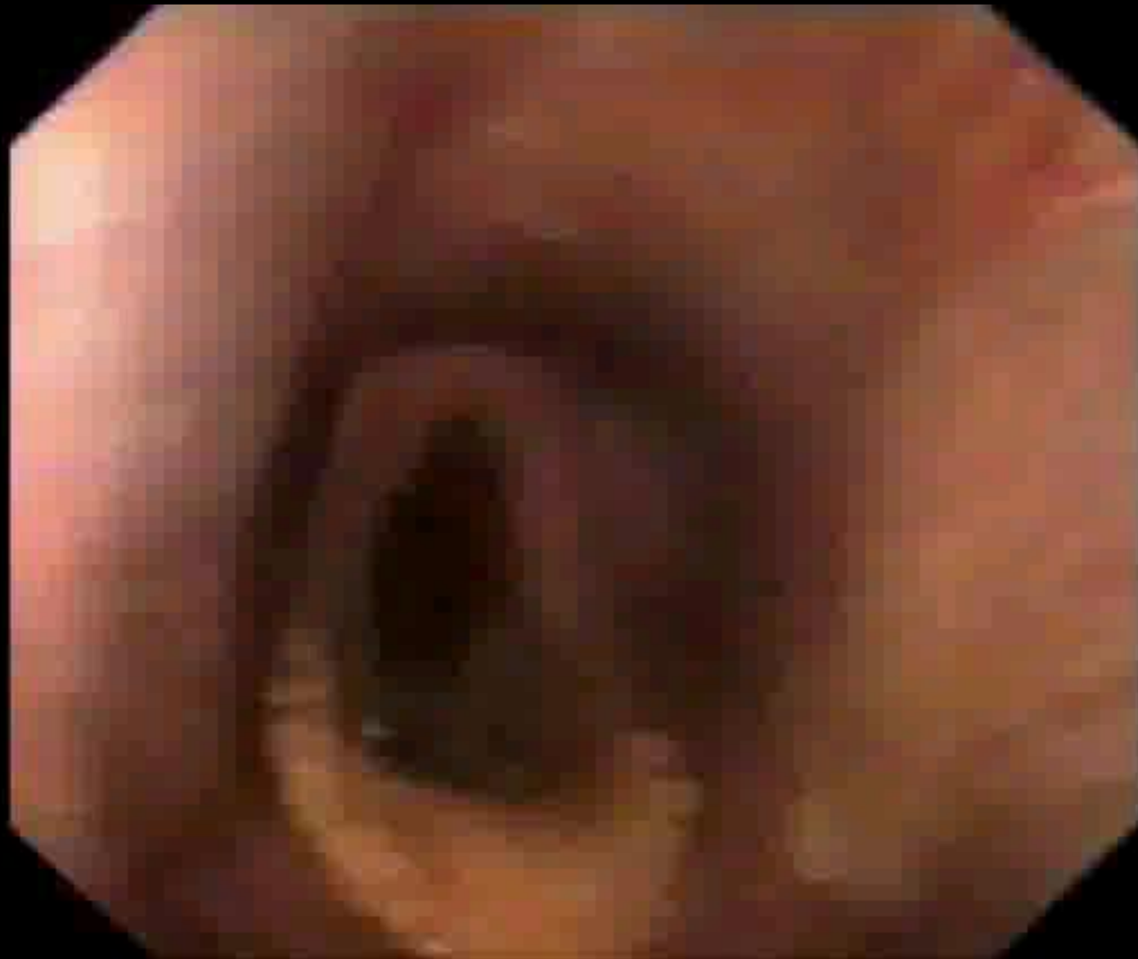
Heart Rate

Respiratory Rate and Volume

Stride frequency at gallop

±132 / min
= 2.2 / sec
= 0.4 s / breath
= 0.2 s / in or out

Left Laryngeal Hemiplegia – "Roarer"



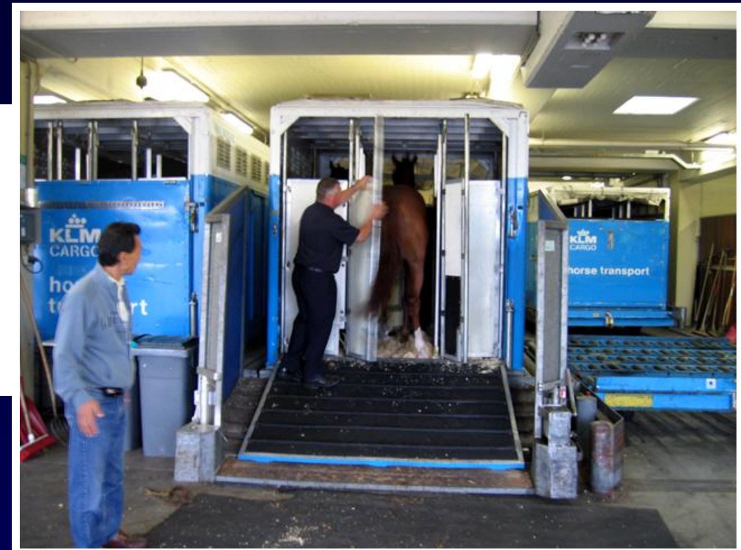
Goals of training

- Training has three major physiological goals
  - develop the musculoskeletal system to be able to withstand the peak loads and stresses that will occur with high-speed running
  - develop the muscles to be able to generate high amounts of metabolic power
  - develop the cardiovascular and respiratory systems to be able to supply large amounts of oxygen to the muscles so they can sustain high metabolic power burning oxygen and not build up lactic acid
- Other goals: mental/psychological, coordination, etc.

Load into air stall, wait & load onto aircraft

Heat

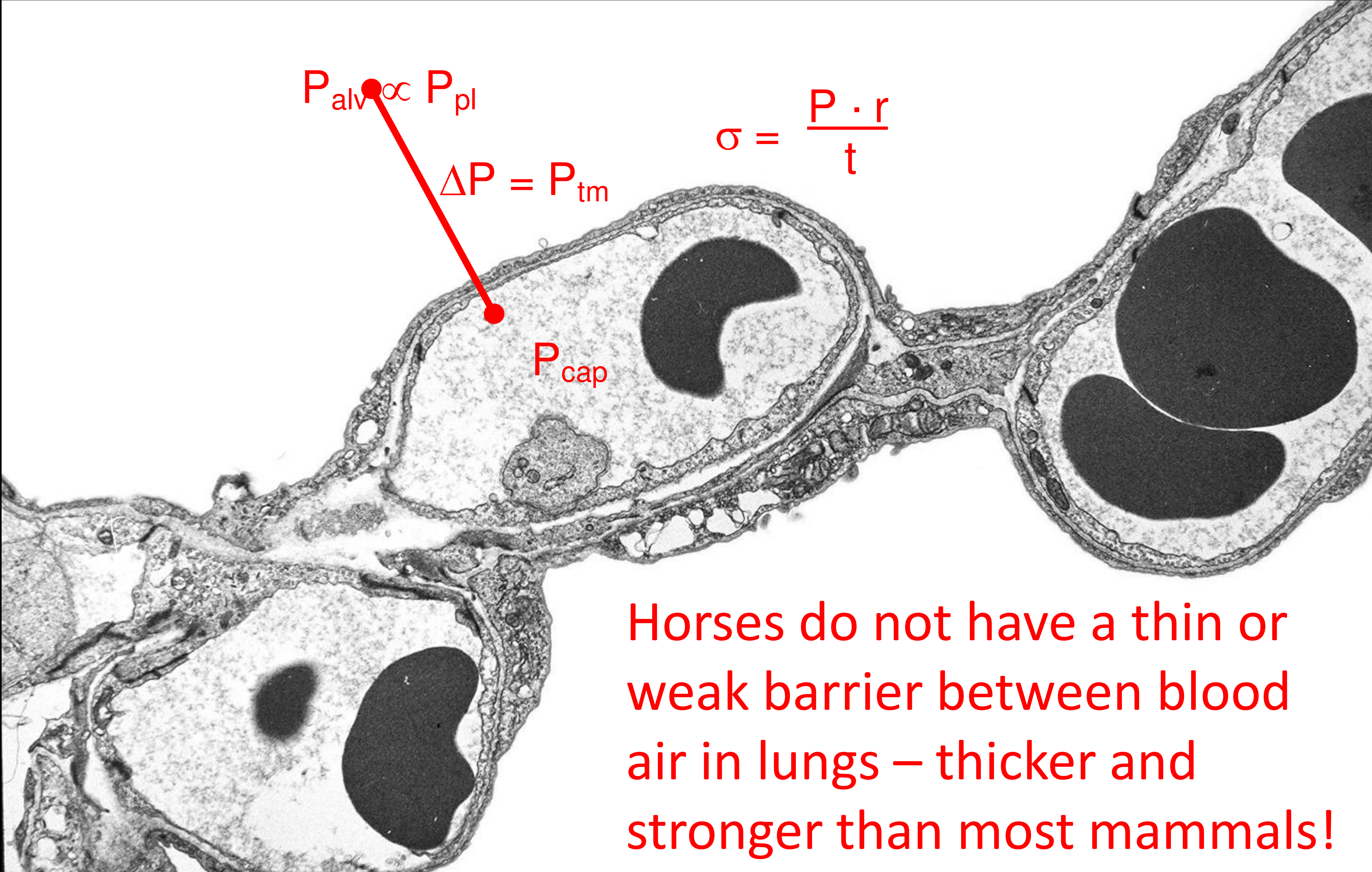
Ventilation



Waiting ….

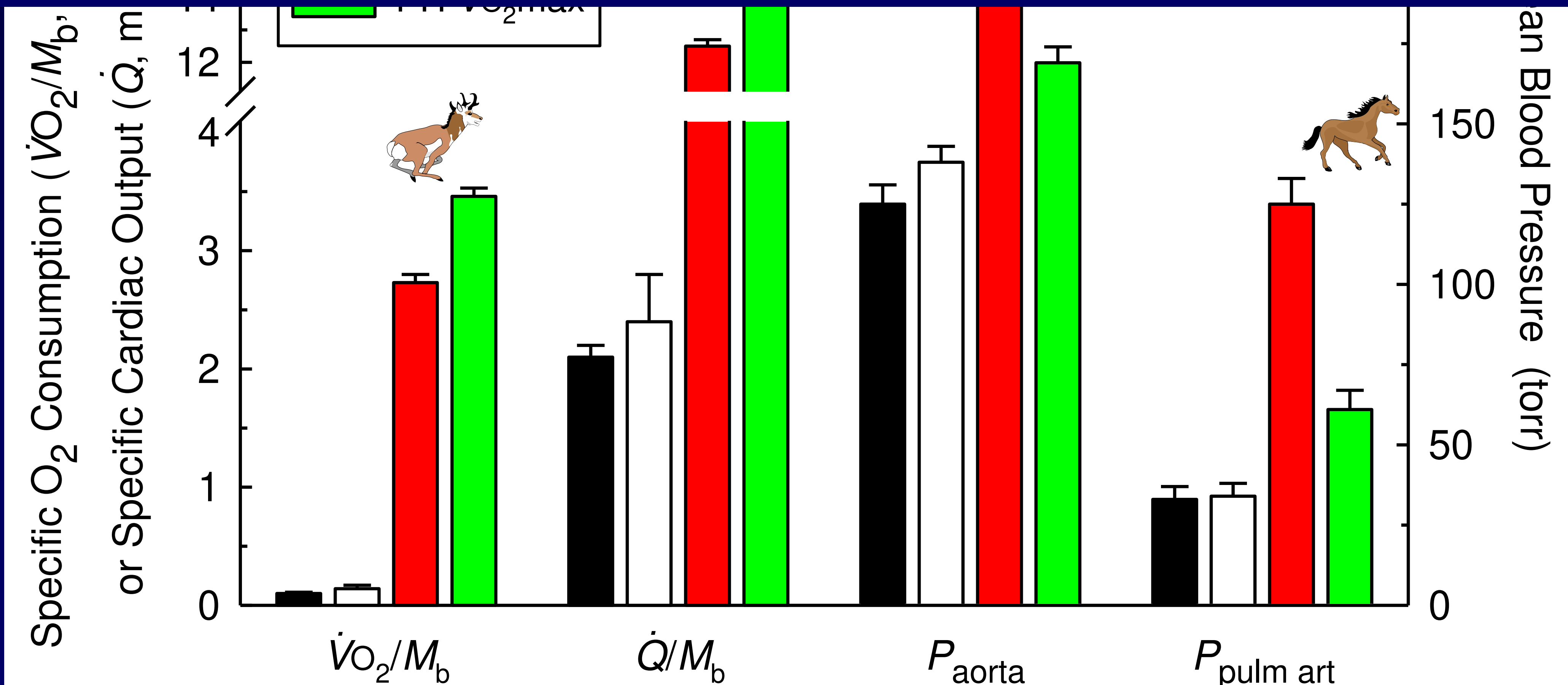
Loading onto airplane

EIPH – "Bleeding"

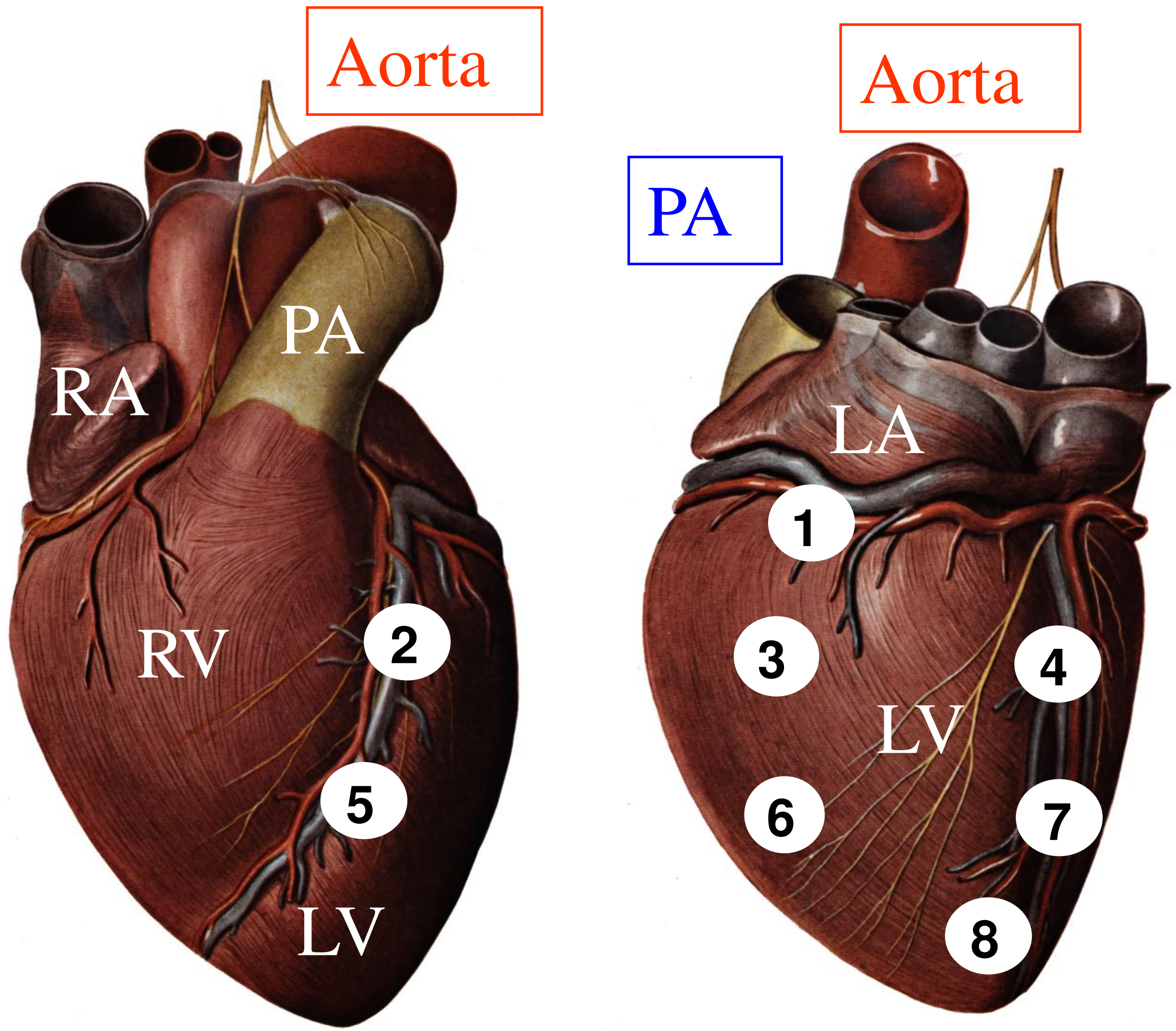

$P_{alv} \propto P_{pl}$
$\sigma = \frac{P \cdot r}{t}$
$\Delta P = P_{tm}$
P_{cap}
Horses do not have a thin or weak barrier between blood air in lungs – thicker and stronger than most mammals!

Pronghorn antelope (PH) *vs.* Thoroughbred (TB)

Pronghorn antelope has higher $\dot{V}O_2max$/kg and $\dot{Q}$/kg but P_{ao} and P_{PA} are much lower. Why is P_{PA} so high in the exercising horse?

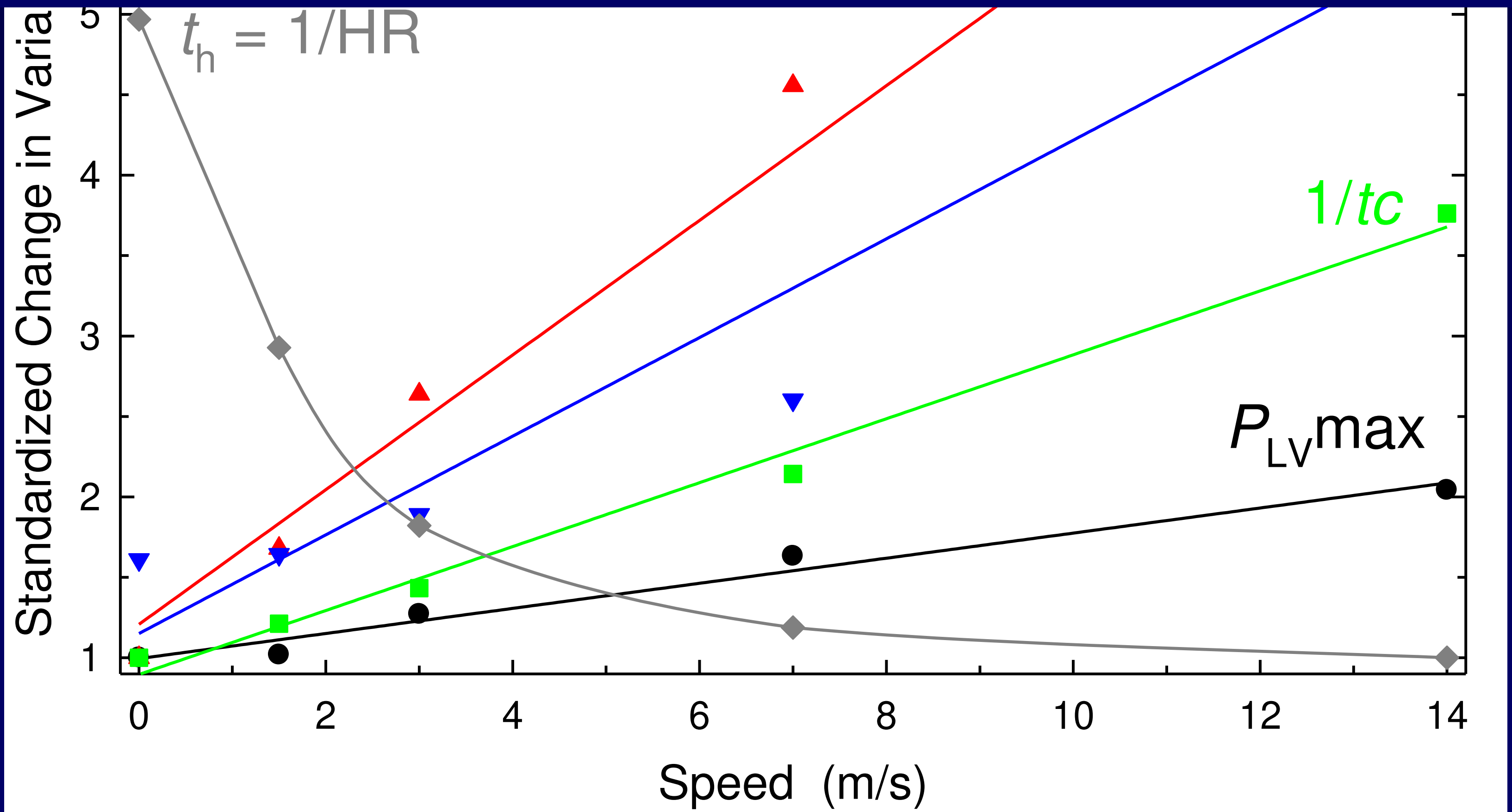


Positions of sonomicrometer crystals on Thoroughbred horse left ventricles

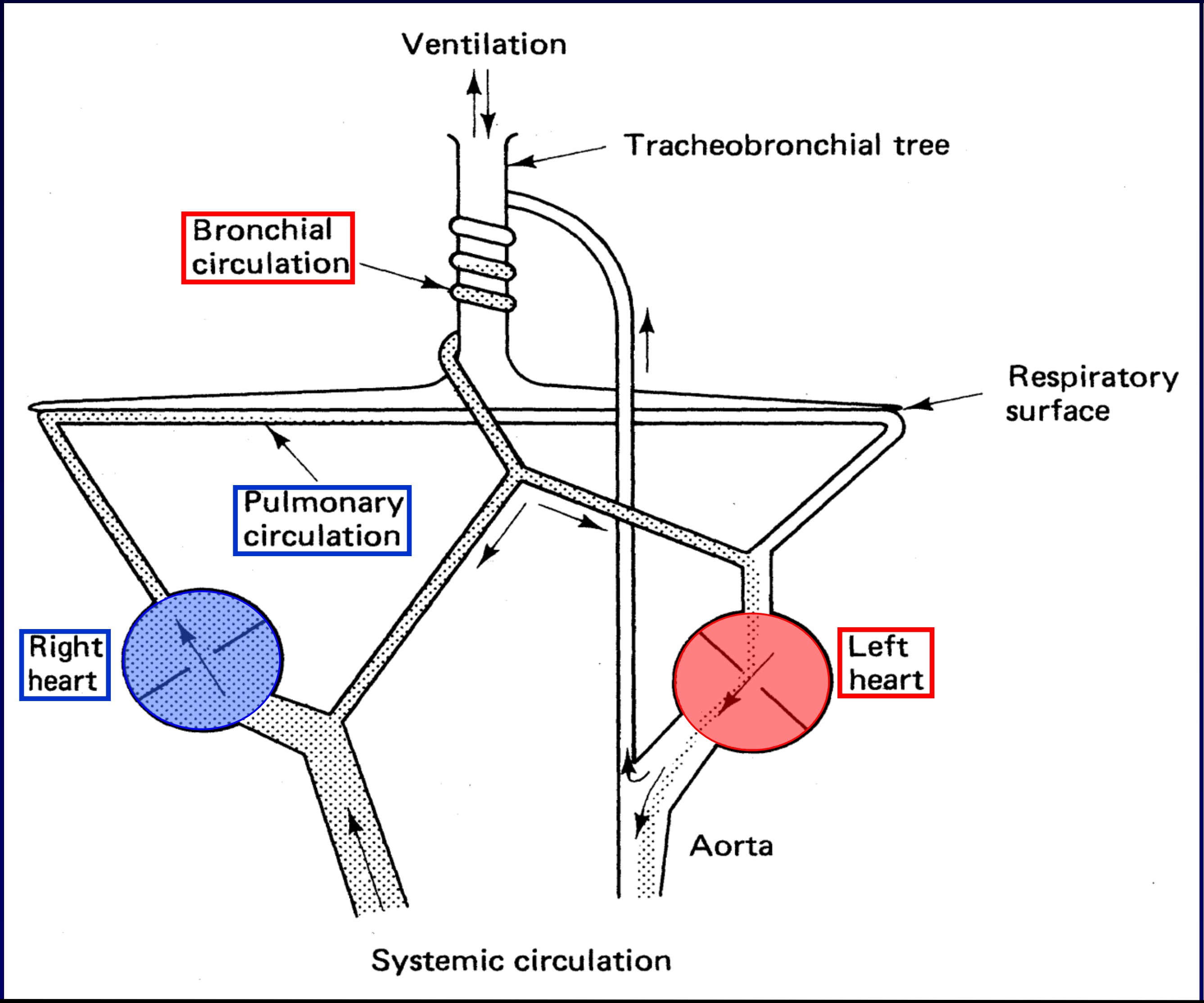


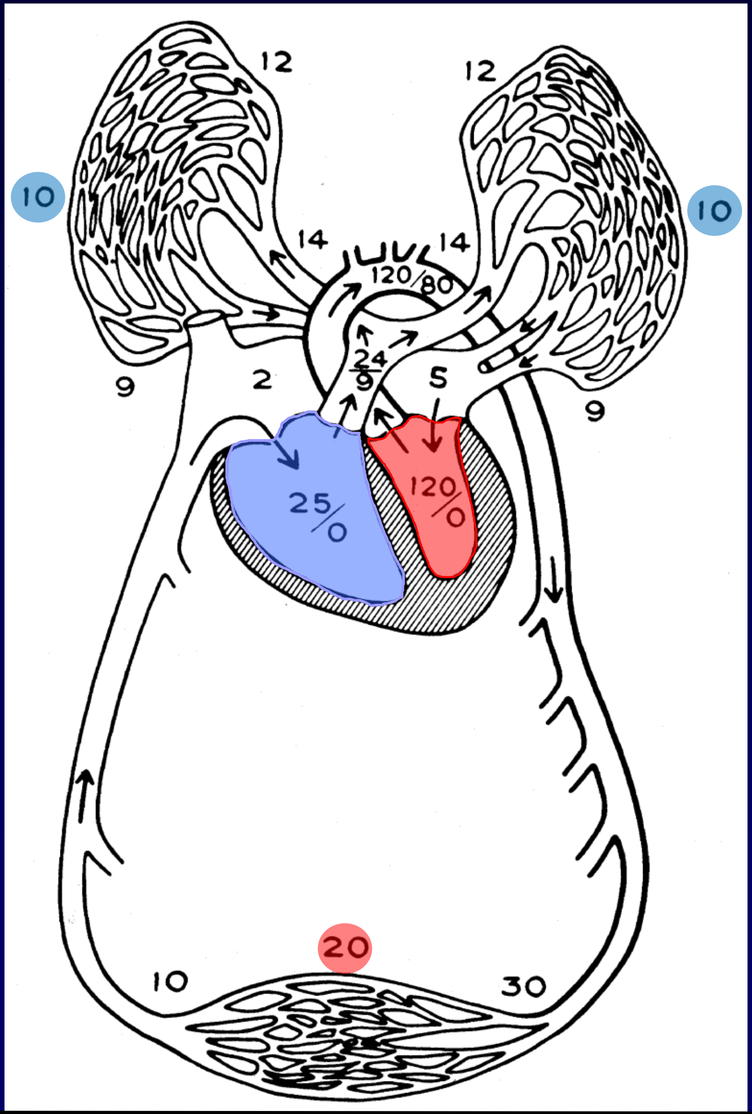
LV pressure generation and relaxation during exercise

Left ventricular relaxation rate does not increase with exercise as much as LV rate of pressure generation – could cause increased diastolic pressure = increased P_{LA}



Origin of EIPH - pulmonary or bronchial?

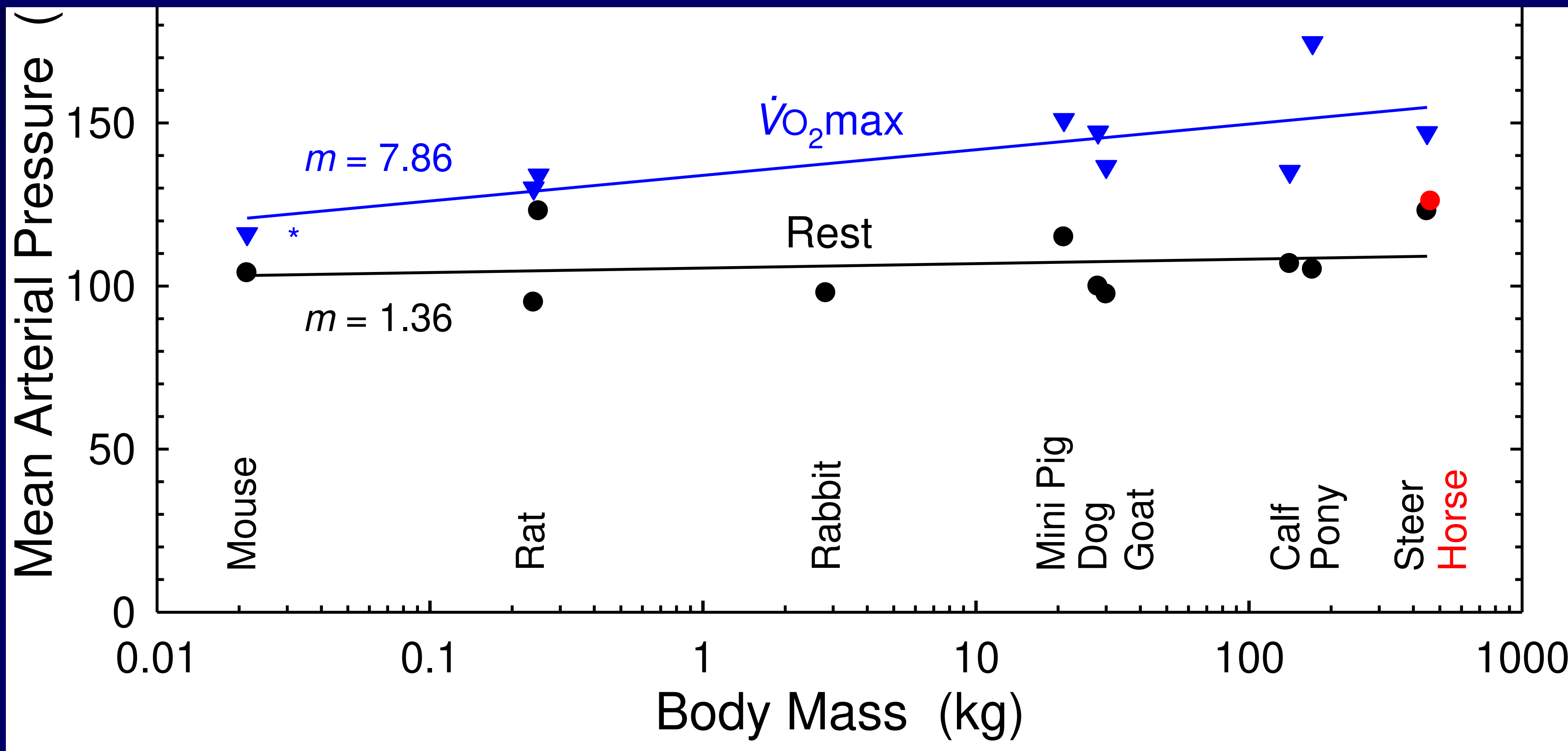




Mean systemic arterial pressure at rest and $\dot{V}O_2max$

Various sources - *J. Appl. Physiol.* and *Am. J. Physiol.*

Despite tendency for larger mammals to have higher arterial pressures at $\dot{V}O_2max$, horses are *exceptionally* high - why?



"Many horses, especially young horses, are oft subject to this bleeding at the nose . . . it proceedeth from much abundance of blood or the vein which endeth in the head is either broken, fretted or opened."

Gervase Markham (1610 (1st ed., 1656 8th ed.)) *Markham's Maister-Peece: Containing All knowledge belonging to Smith, Farrier, or Horse-Leach, touching the curing of all diseases in Horses*

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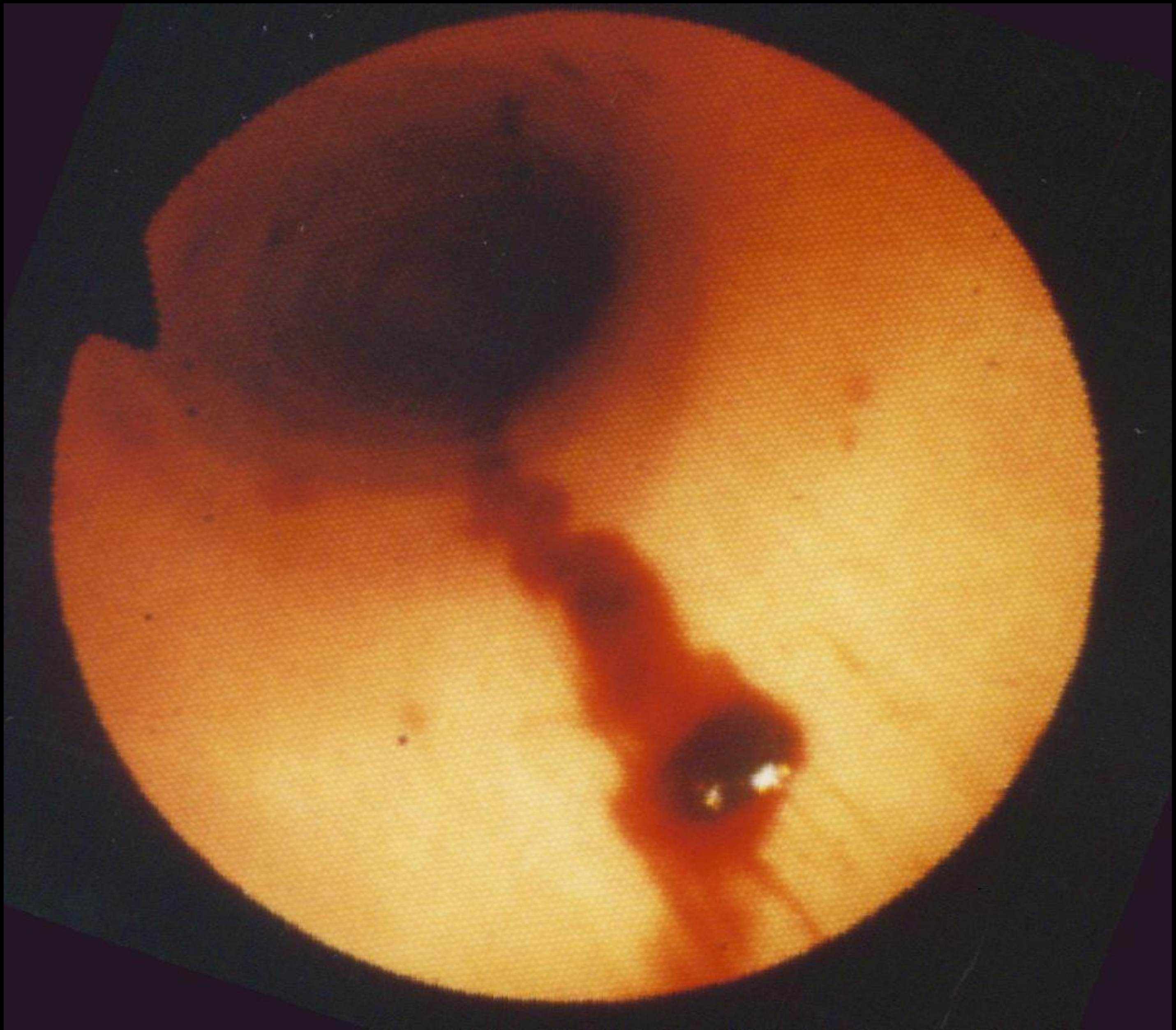
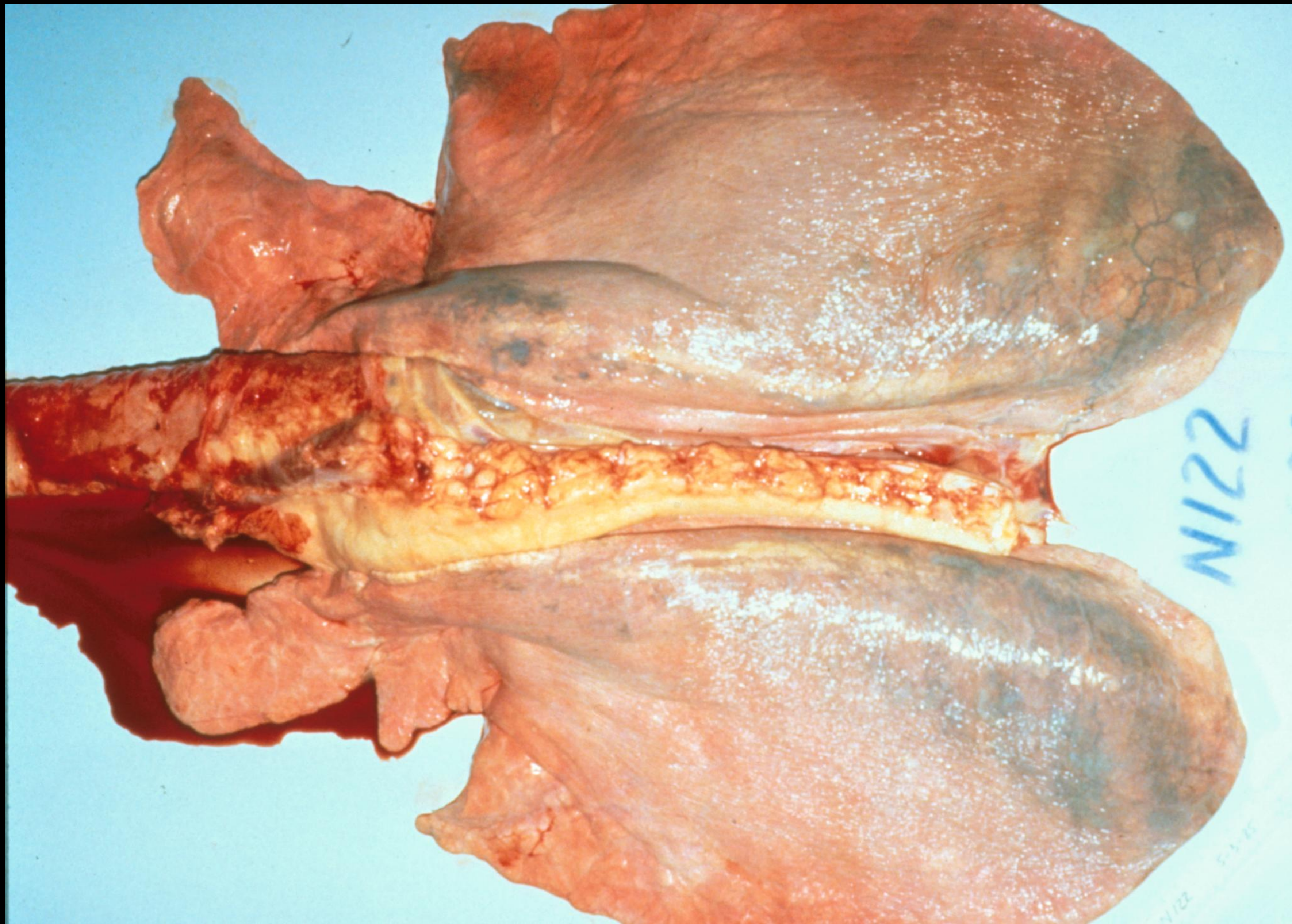
"...no work...has done more damage to veterinary progress."
(J.F. Smithcors and A. Smithcors (1997))

Fiberoptic Endoscopy

EIPH blood in airways originates in lungs



EIPH lesions – caudodorsal lungs



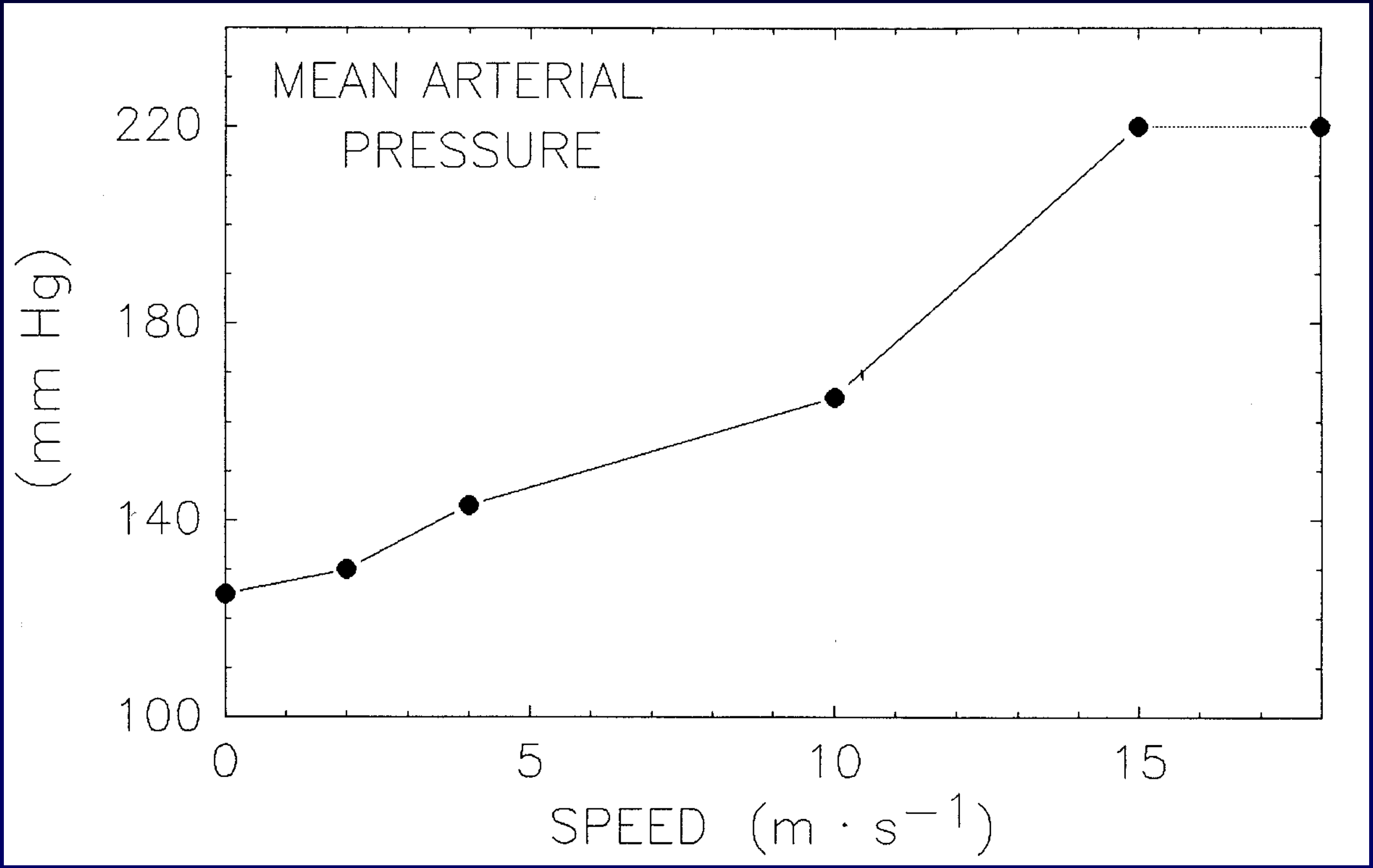
Exercise-Induced Pulmonary Hemorrhage

- J.R. Pascoe *et al.* (1981) *Am. J. Vet. Res.*
  44% bronchoscopy; EIPH, “bleeding”

- C.R. Sweeney (1991) *Vet. Clin. North Am. Equine*
  TB: 44-95%; *App:* 52%; *SB:* 26%

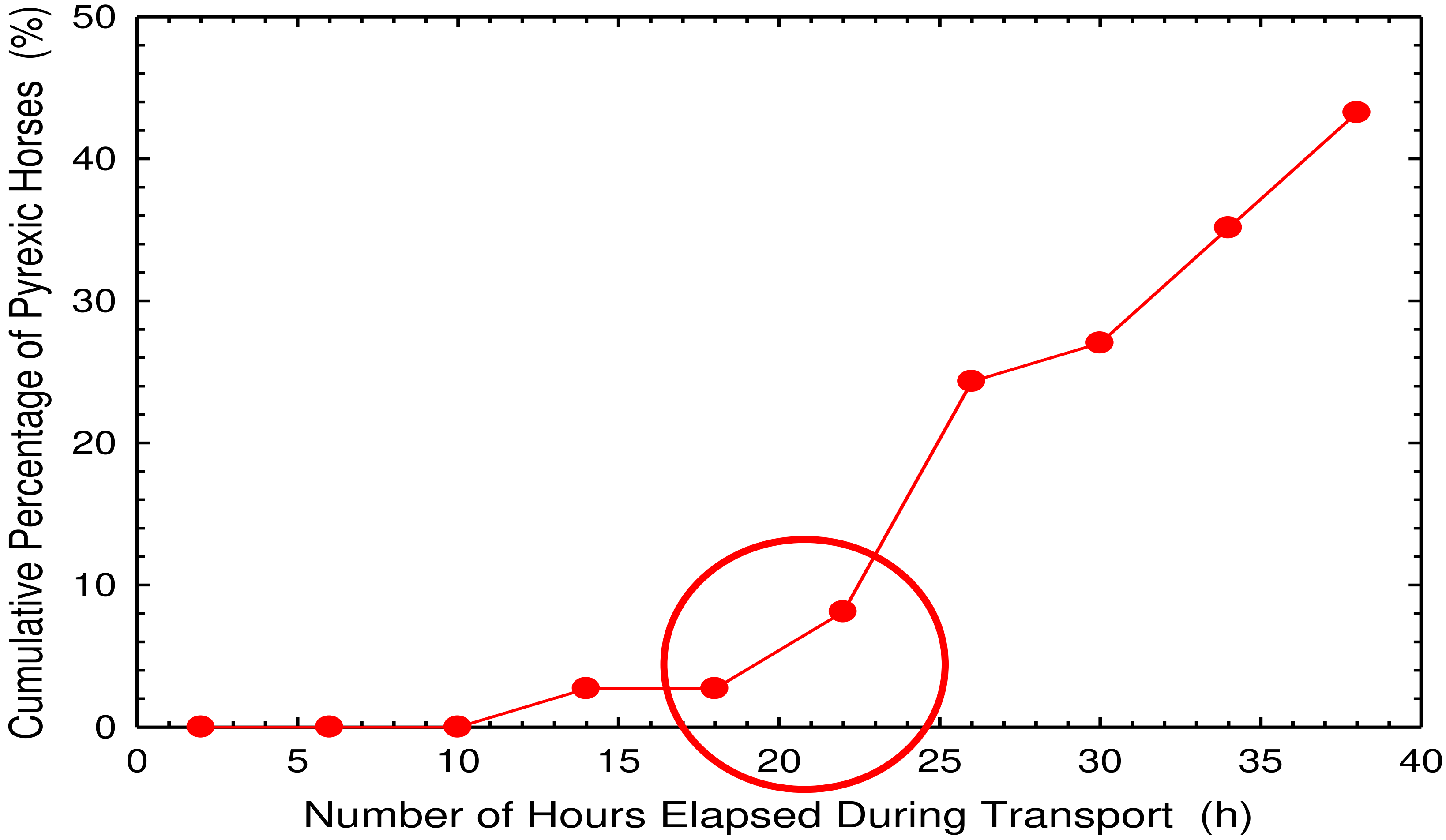
- K.E. Whitwell and T.R.C. Greet (1984) *Equine Vet. J.*
  Tracheal wash - hemosiderophages - 100%

Blood pressures in horses are much higher than in most mammals

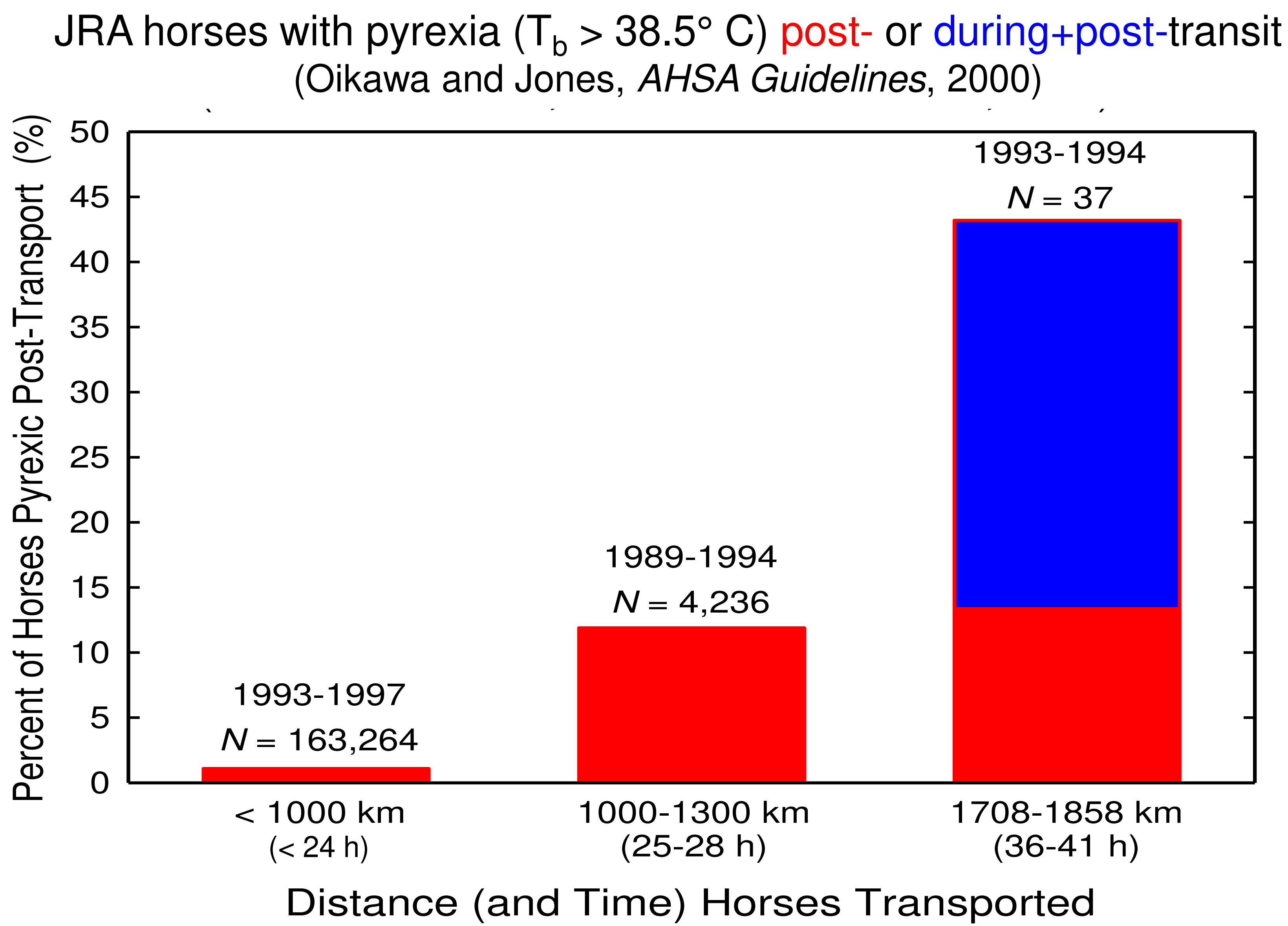


Transport Time and Risk of Shipping Fever

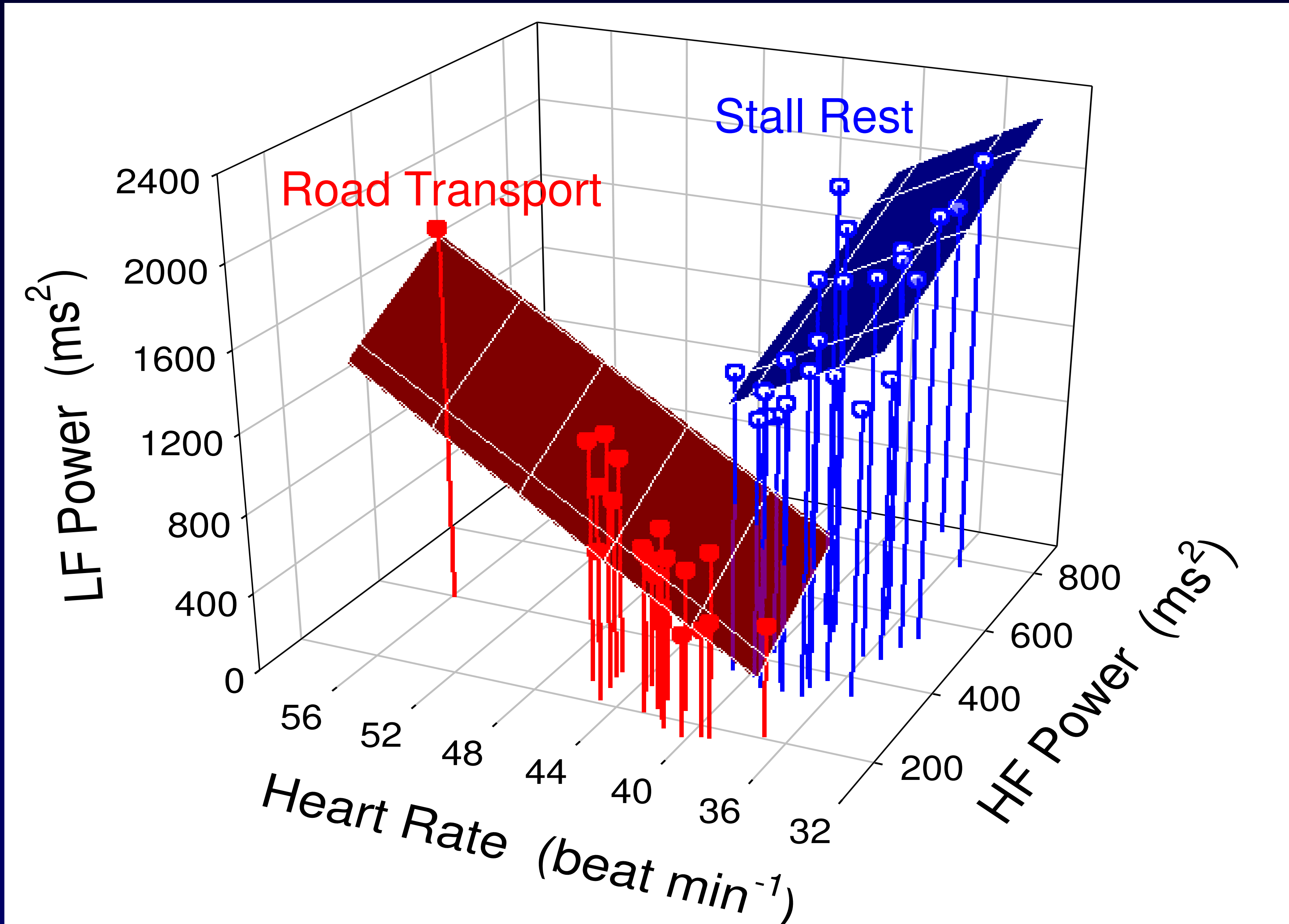
3 year-old JRA Thoroughbreds prior to registration as racehorses (*N* = 37)
(Oikawa and Jones, *AHSA Guidelines*, 2000)



Transport Time and Risk of Shipping Fever



Heart RateVariability in Stall and Road Transport




9 25 '98

Nihon Tei-en in Davis, California