Cardiovascular Response to Gravitational Stress

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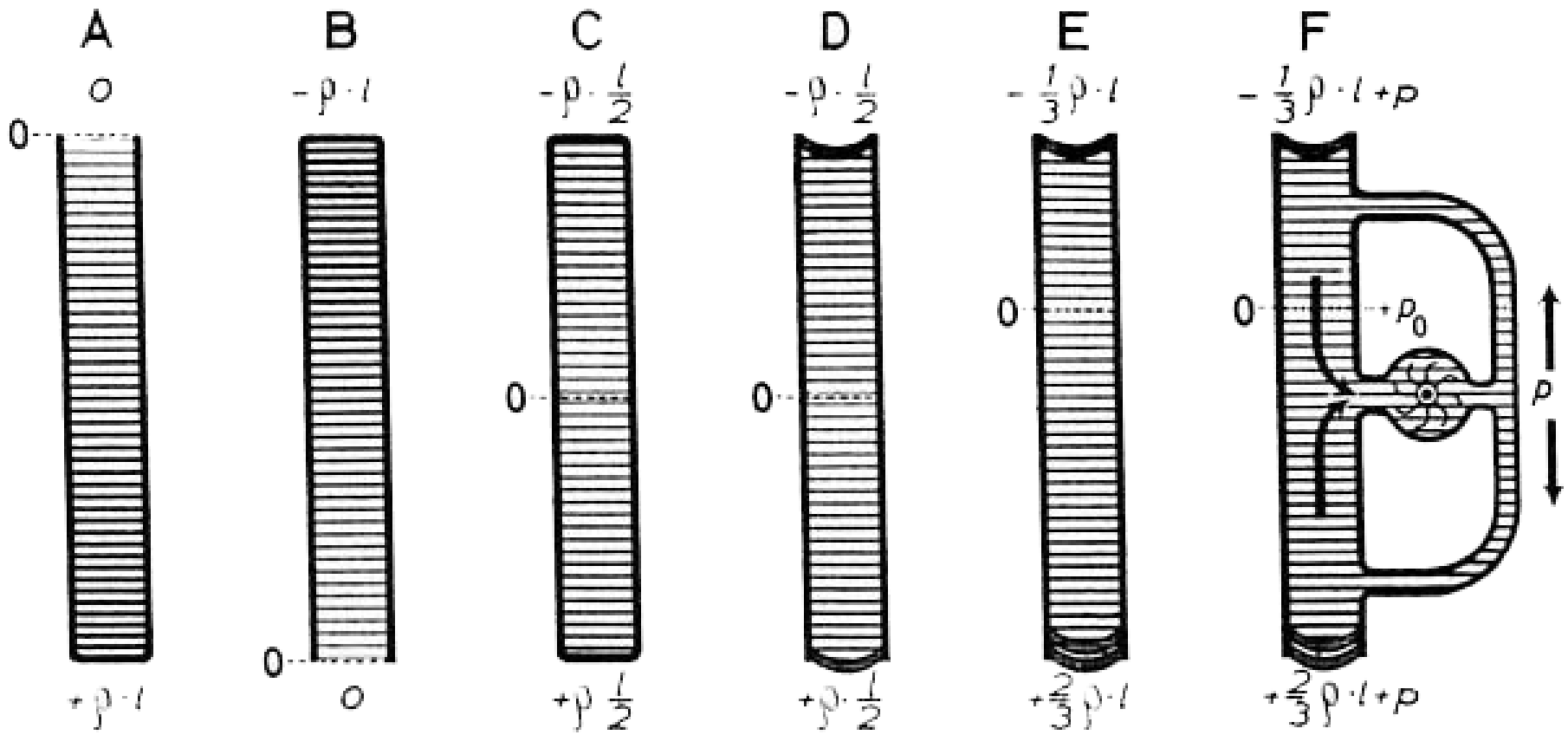
Goals

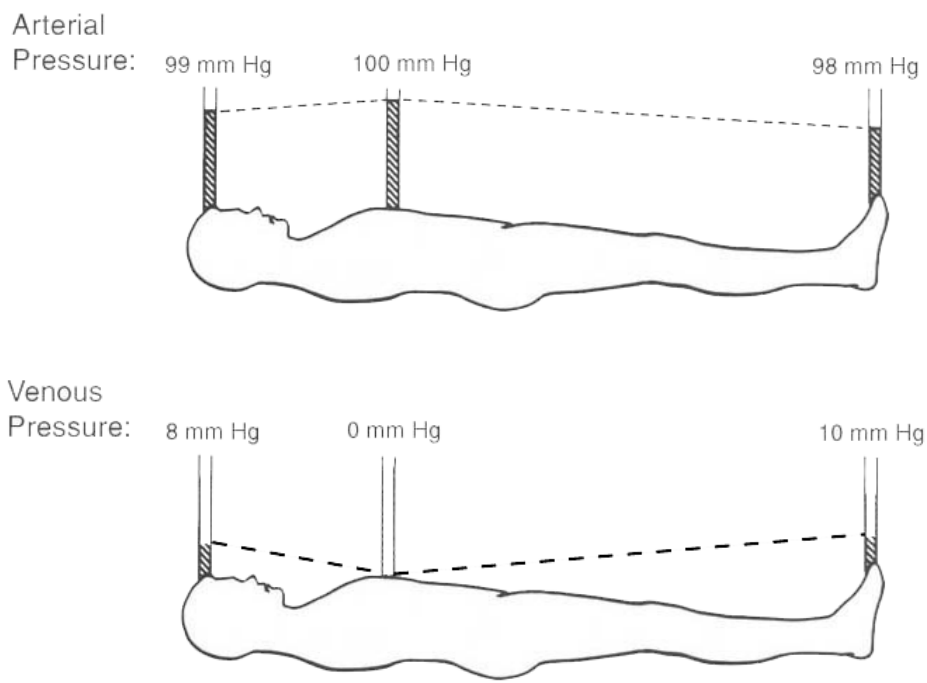
- Synthesize concepts developed last week to understand cardiovascular response to gravitational stress
- Briefly review spaceflight-related cardio-vascular problems
- Consider modeling approach to understand post-flight orthostatic intolerance

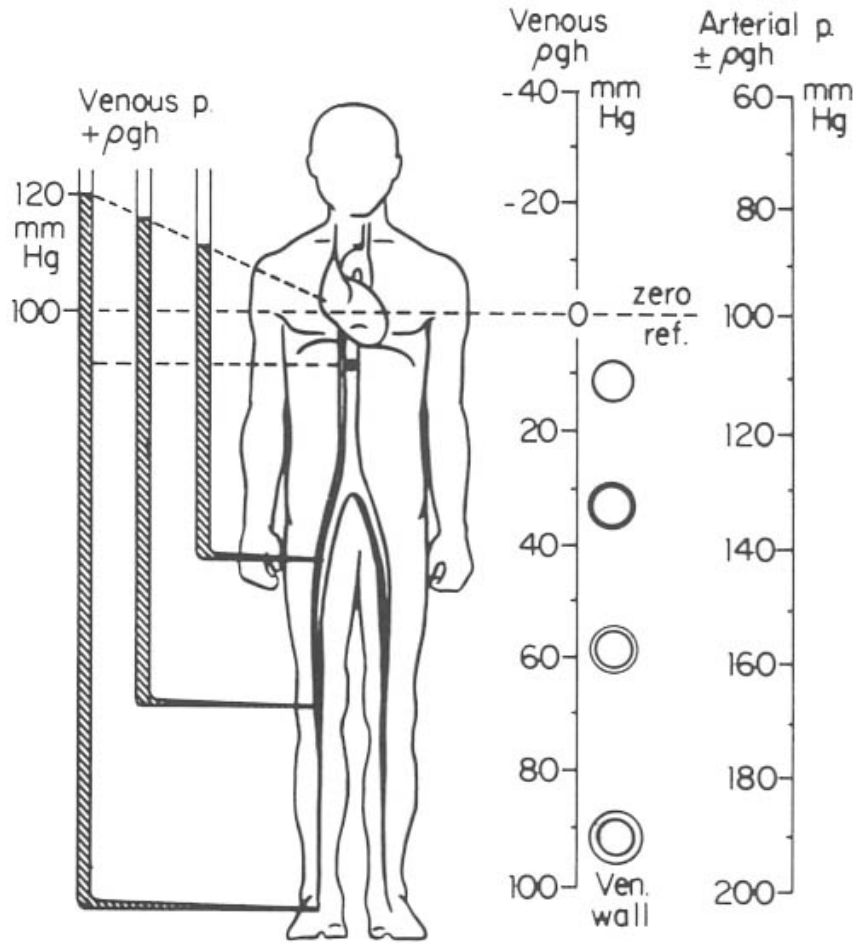
Hydrostatic Pressure



adapted from: Clark, Hooker, Weed. Am. J. Physiol. 109:166, 1934.

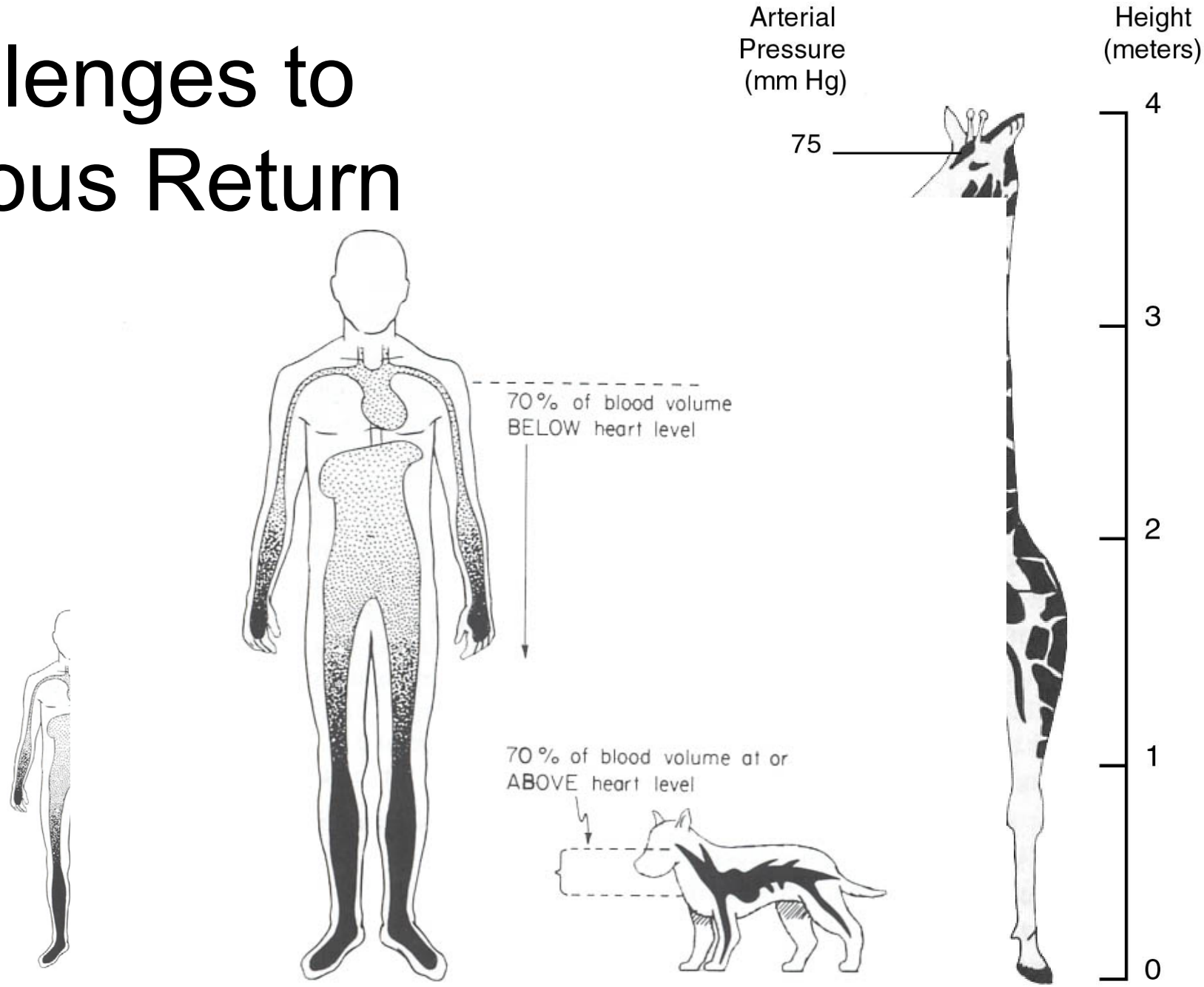
Hydrostatic Pressure in the Circulation





adapted from: L.B. Rowell (1986) Human Circulation. Regulation during Physical Stress.

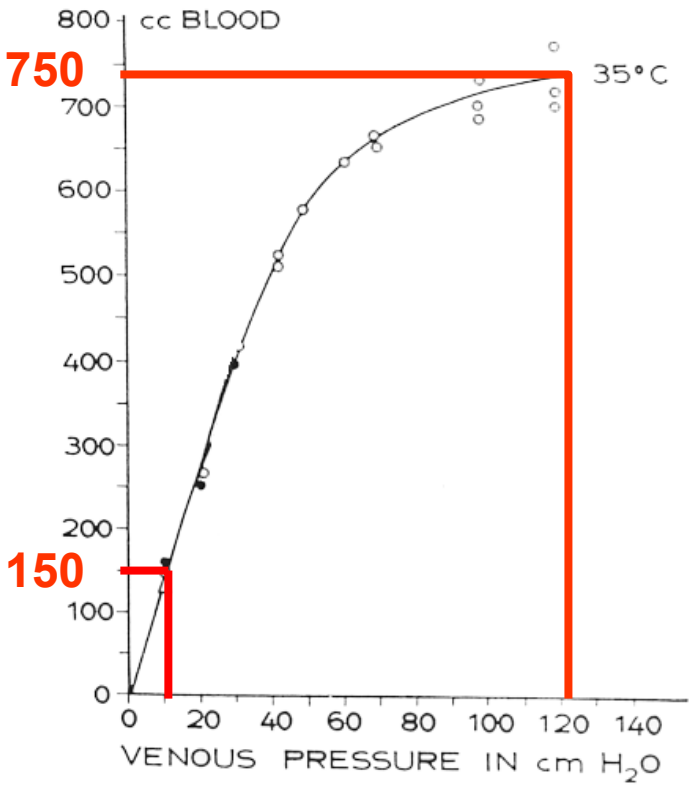
Challenges to Venous Return



adapted from: L.B. Rowell (1986) Human Cardiovascular Control.

Venous Pooling

Pressure-Volume relation
for both legs



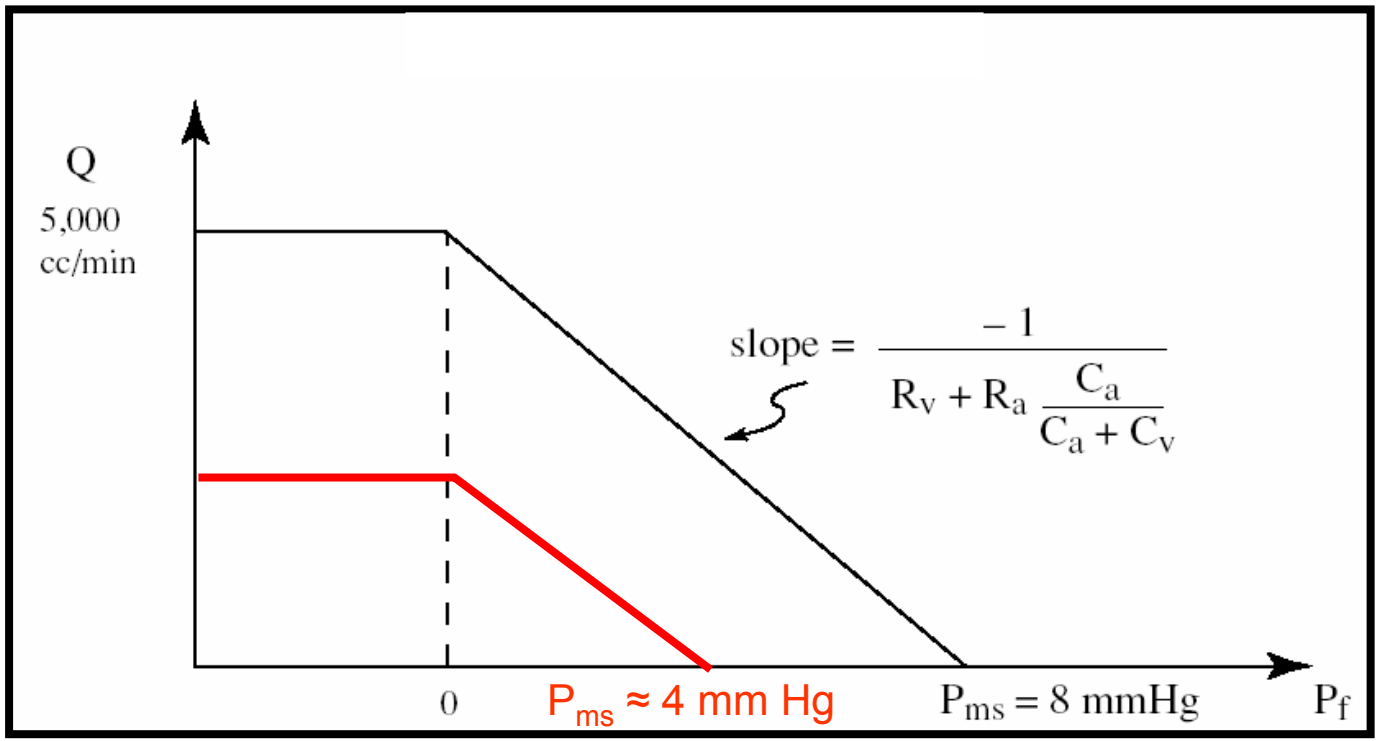
$\Delta V \approx 600$ ml

Standing up can be conceptualized as a 600 ml-reduction in circulating volume.

adapted from: Gauer and Stone. Handbook of Physiology, 1965.

Venous Return Curve

(no control)



$V_{total} \approx 5000$ ml
$V_{ZPFV} \approx 3900$ ml
$C_{total} \approx 125$ ml/mmHg

$P_{ms} \approx 8$ mm Hg

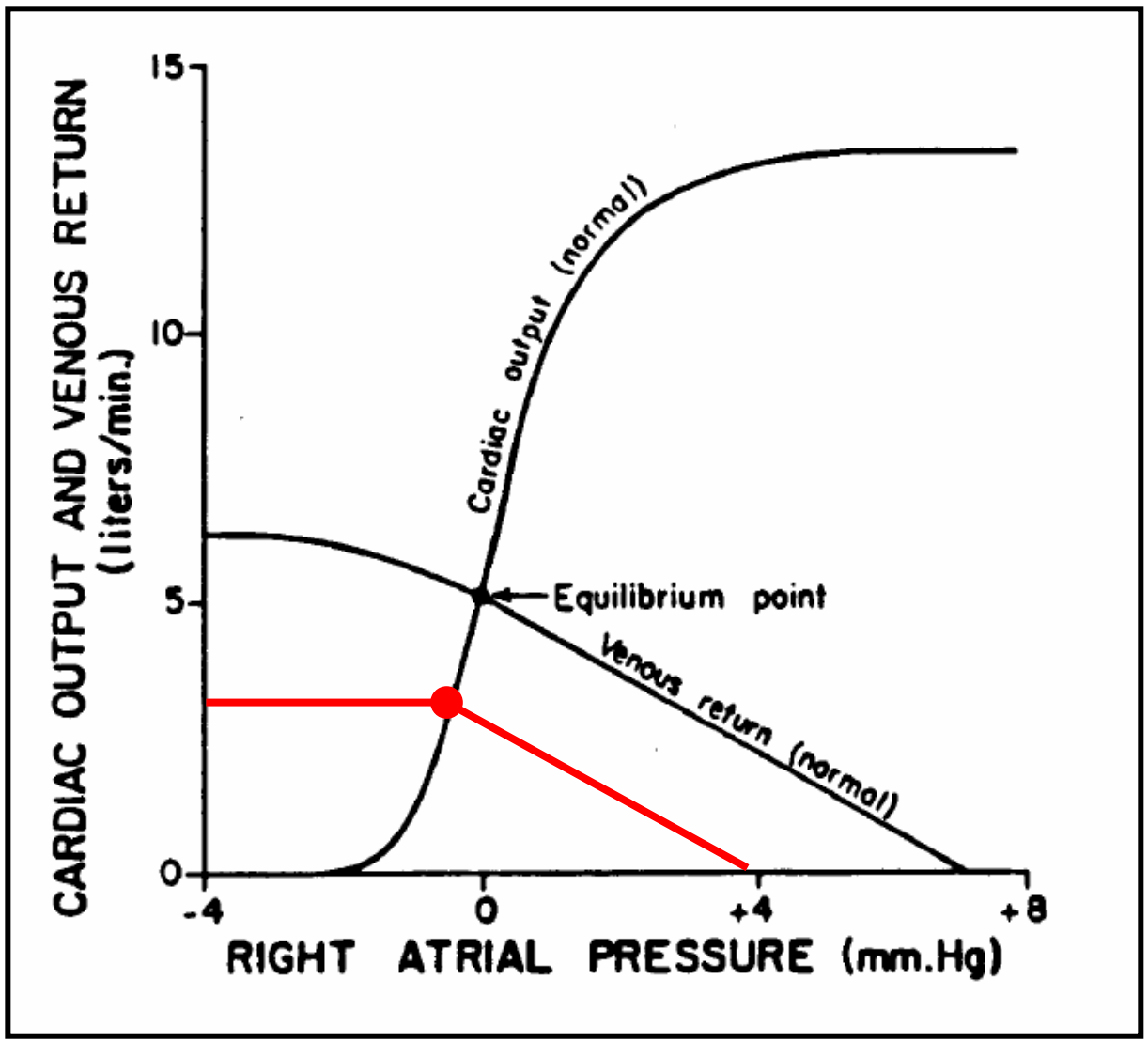
$$P_{ms} = \frac{V_{total} - V_{ZPFV}}{C_{total}}$$

$V_{total} \approx 5000$ ml
$V_{ZPFV} \approx 4500$ ml
$C_{total} \approx 125$ ml/mmHg

$P_{ms} \approx 4$ mm Hg

Intact Circulation

(no control)



Is a 50%-reduction in CO a lot?

Remember Ohm's law:

$$\Delta V = R \cdot I \qquad \Leftrightarrow \qquad \Delta P = TPR \cdot CO$$

Since TPR = const (no control), a 50 %-reduction in CO leads to a 50%-reduction in perfusion pressure.

Autonomic Failure

(disorder of the autonomic nervous system)

Head-up tilt to 70° in 6 patients with pure autonomic failure.

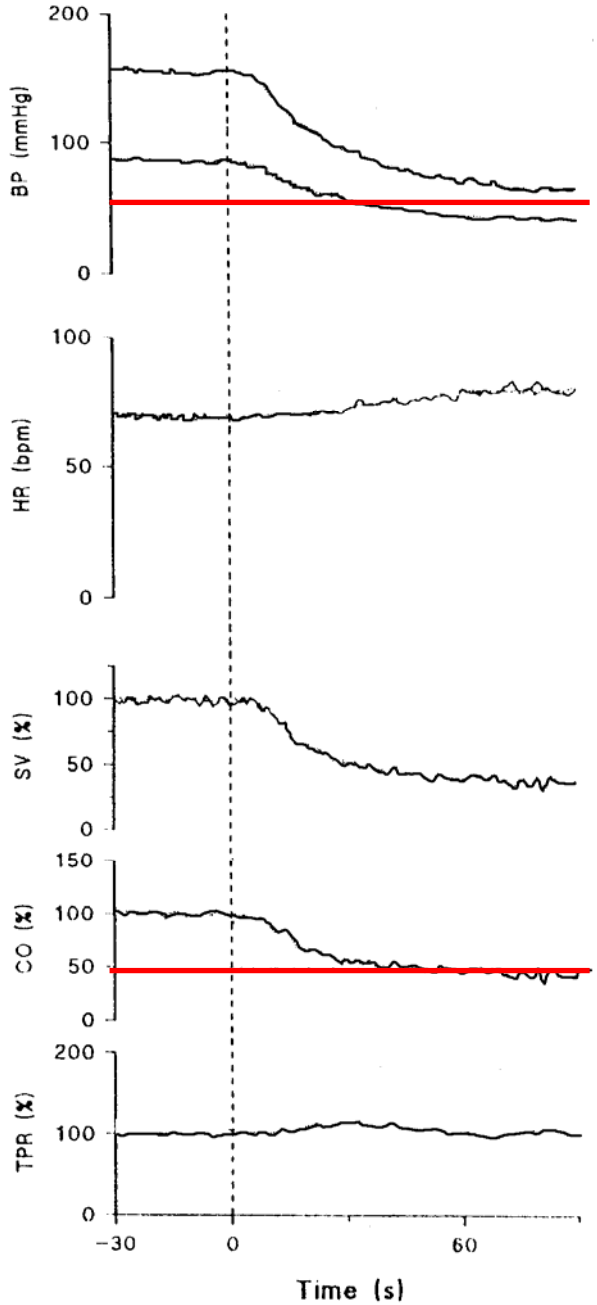
BP recorded at heart-level:

MAP ≈ 50 mmHg

BP expected at eye-level:

MAP = 50 mmHg - ρgh
≈ 20-30 mmHg

Blackouts occur!



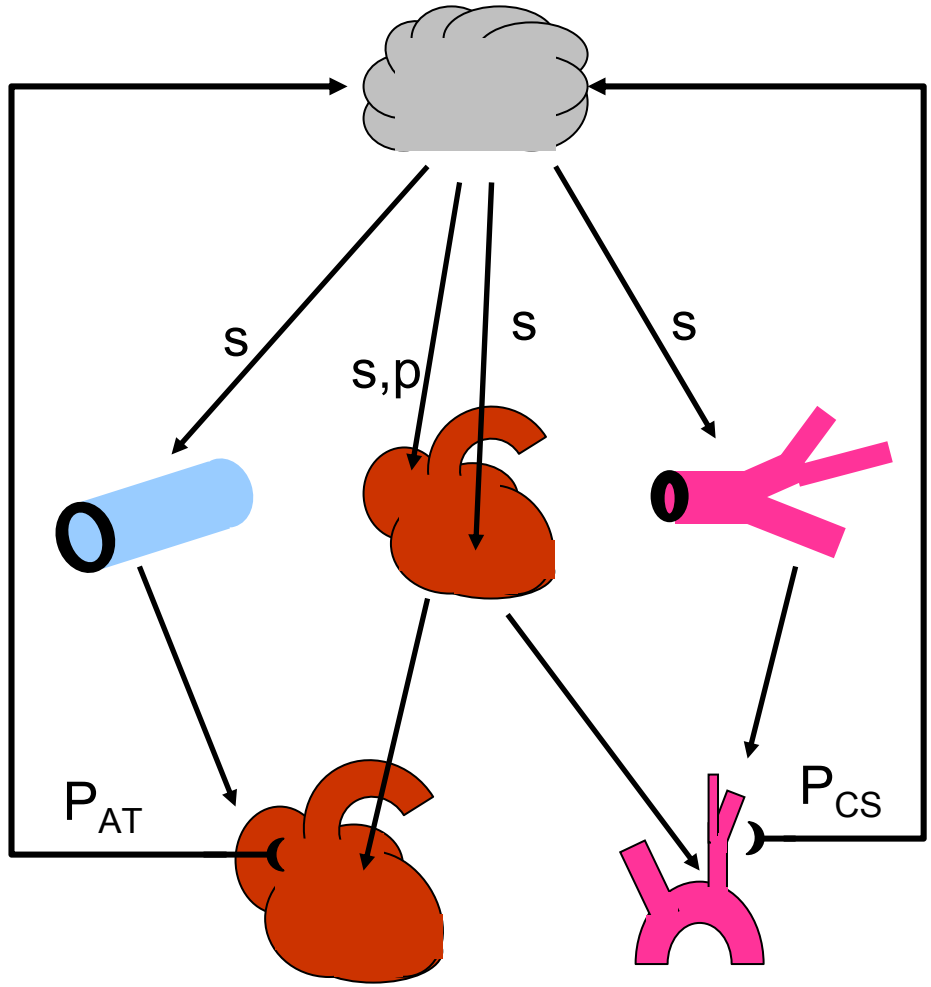
adapted from: Wieling et al. Clin Sci 1998; 94: 347.

Preliminary Conclusions

- Gravity imposes a **SERIOUS** stress upon the cardiovascular system.
- To withstand this stress, control of circulatory parameters is imperative.

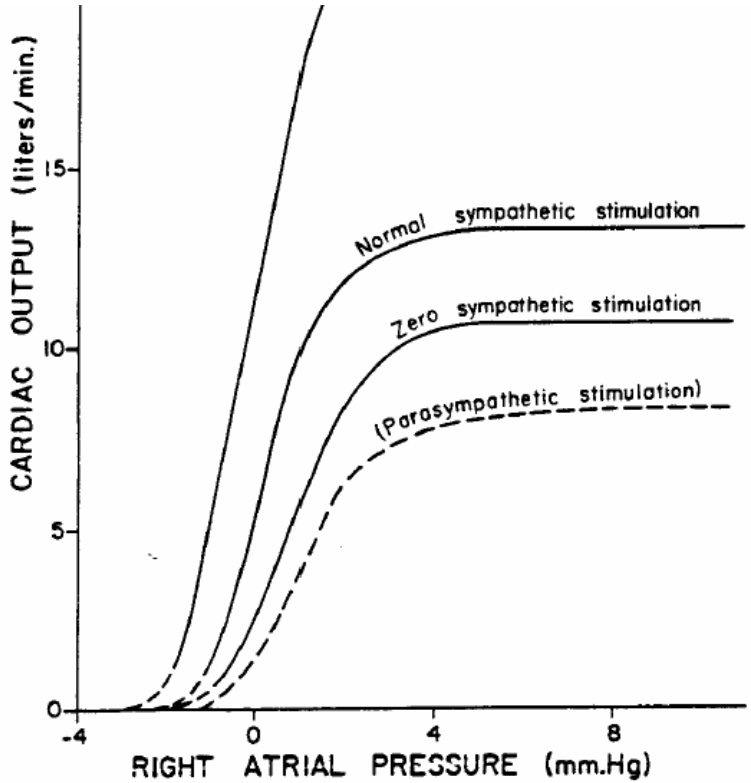
Circulatory Control

- Arterial Baroreflex
- Cardiopulmonary reflex
- Effector mechanisms:
  heart rate,
  venous tone,
  cardiac contractility, and
  arteriolar resistance

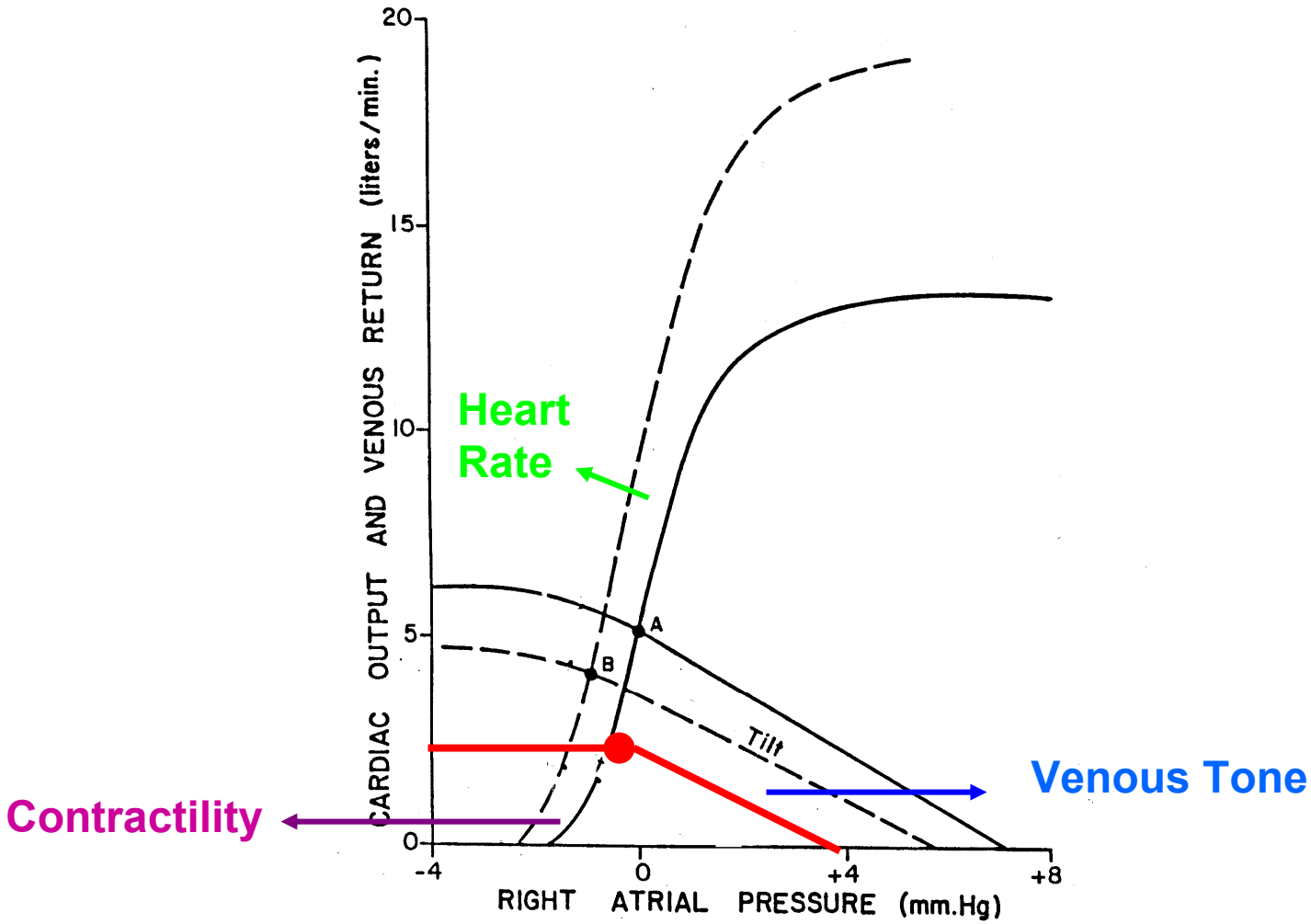


Effects on the cardiac output curve of different degrees of sympathetic and parasympathetic stimulation.

Sympathetic Stimulation



Effects of Control



Normal Physiology

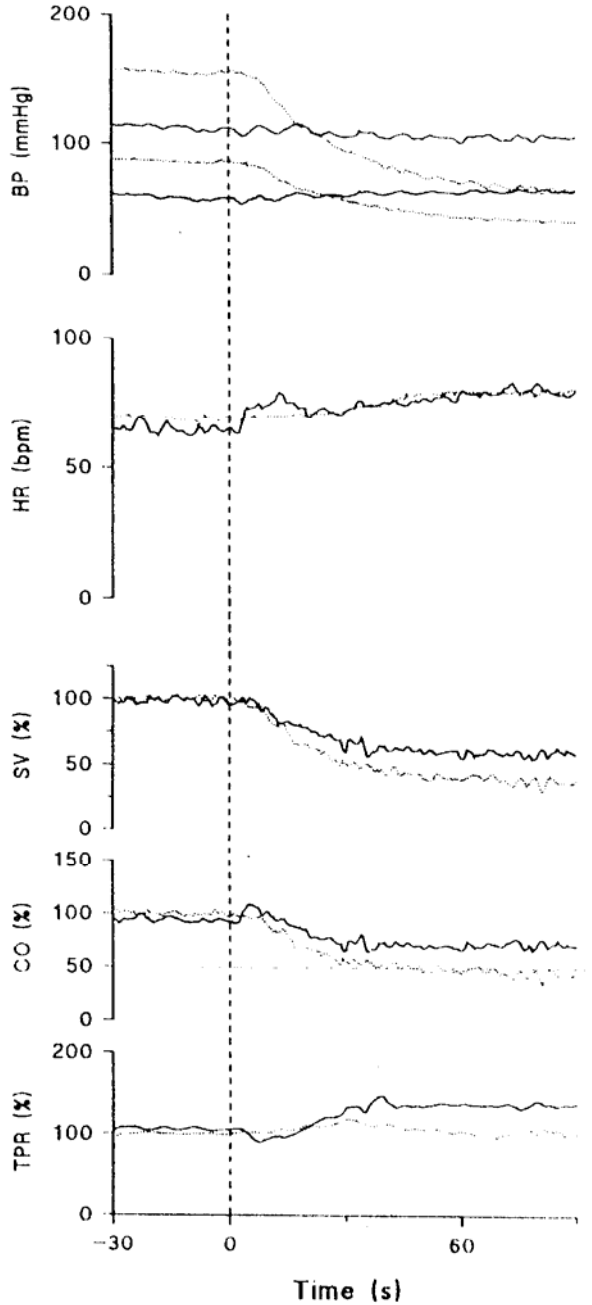
Head-up tilt to 70° in 6 patients with pure autonomic failure (dotted lines) and 6 normal volunteers (solid lines).

BP recorded at heart-level:

MAP ≈ 90 mmHg

BP expected at eye-level:

MAP = 90 mmHg - ρgh
≈ 60-70 mmHg

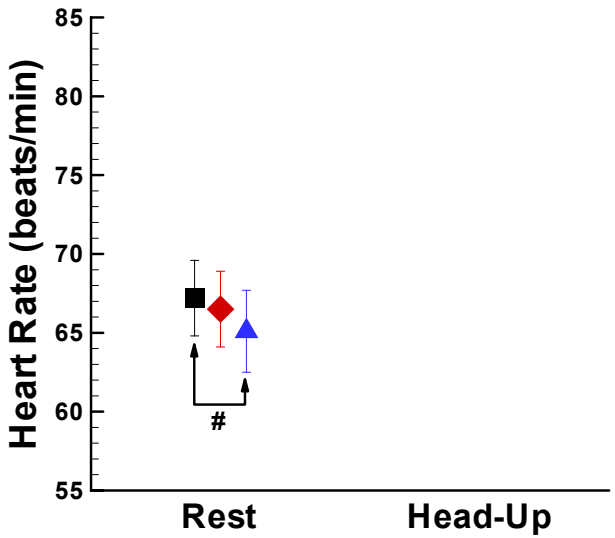


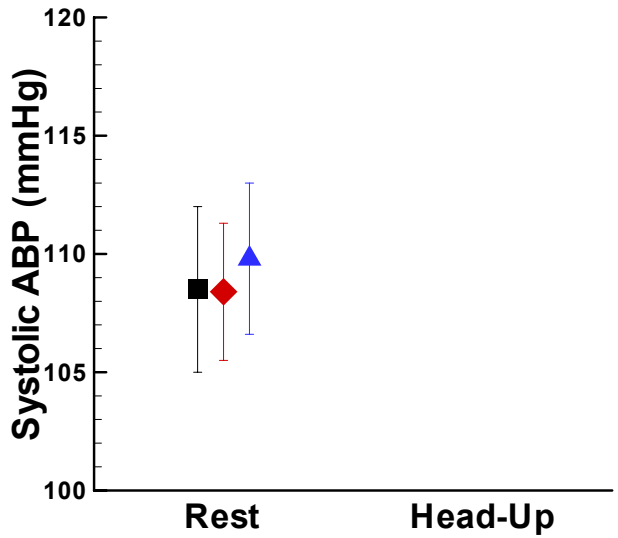
adapted from: Wieling et al. Clin Sci 1998; 94: 347.

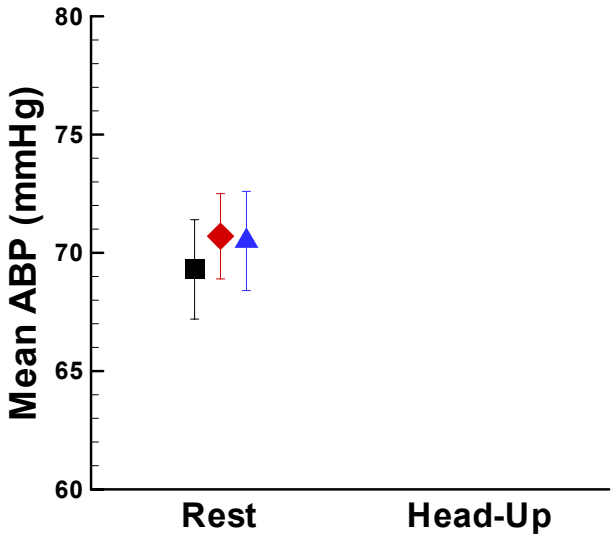
Steady-state responses

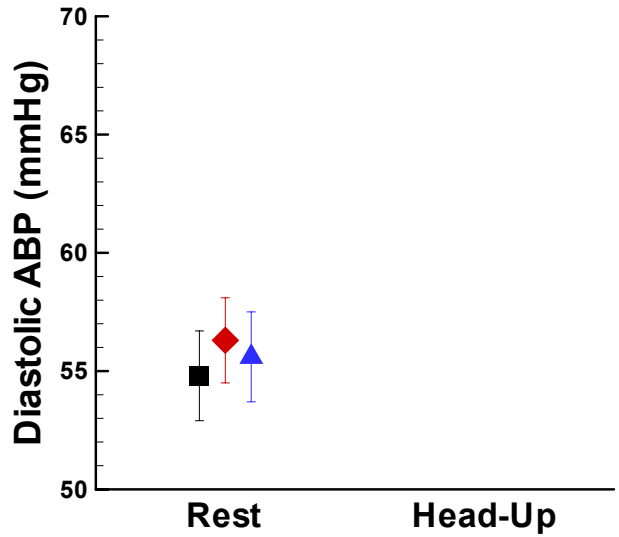
▲ : Stand-up
◆ : Slow tilt
■ : Rapid tilt

: mean ± SE
N = 20









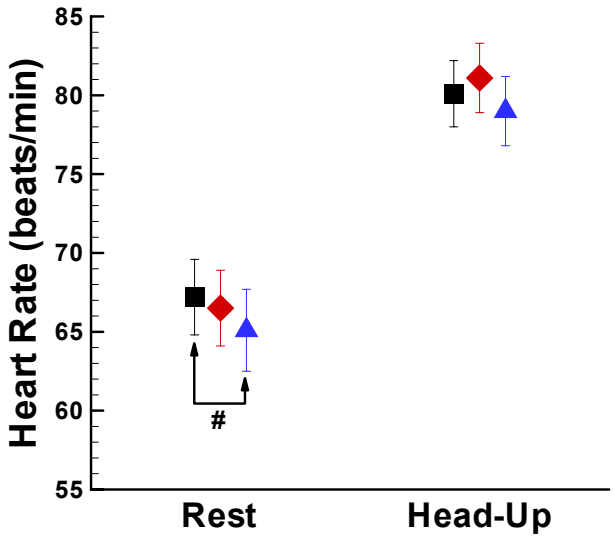
# P < 0.05

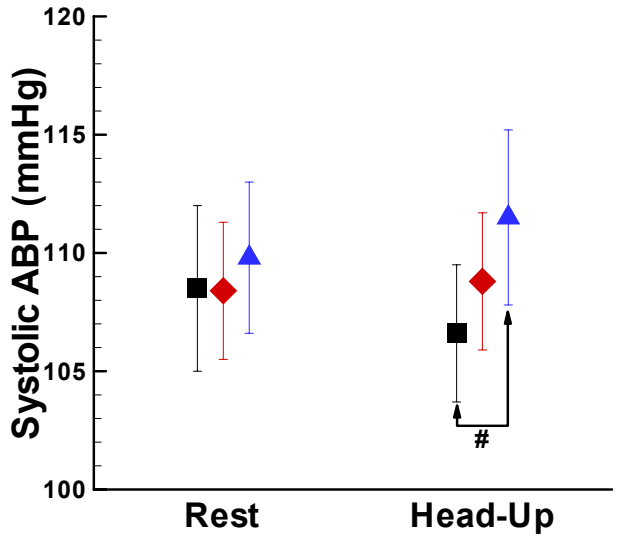
Steady-state responses

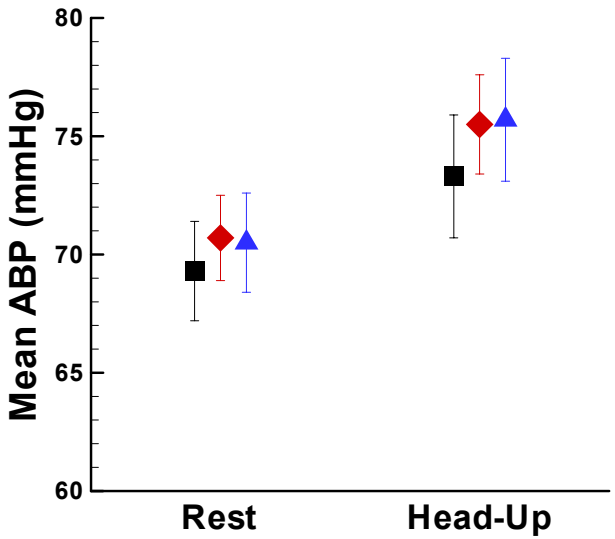
: Stand-up
: Slow tilt
: Rapid tilt

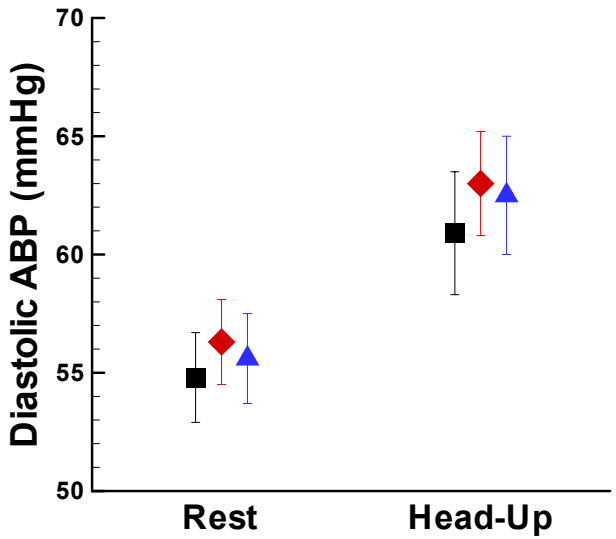
: mean ± SE
N = 20

# P < 0.05









Steady-state responses

▲ : Stand-up

◆ : Slow tilt

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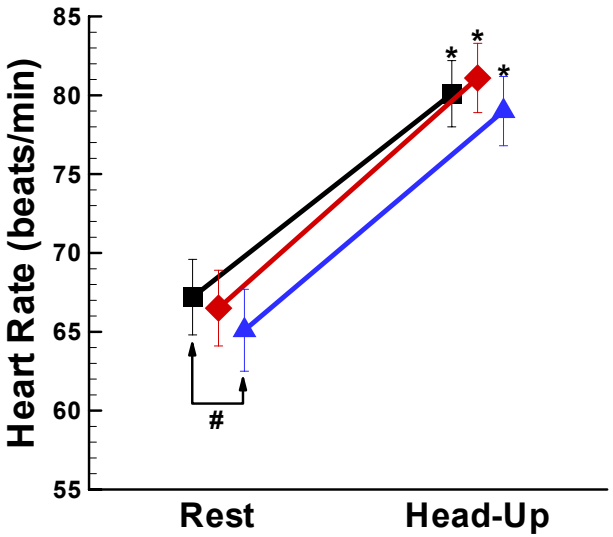
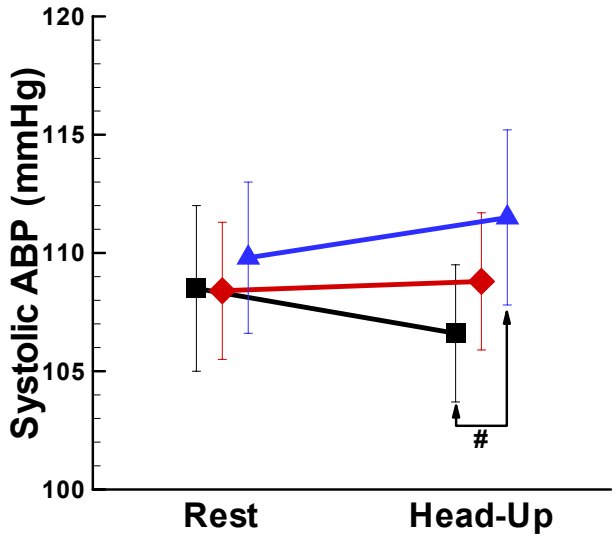
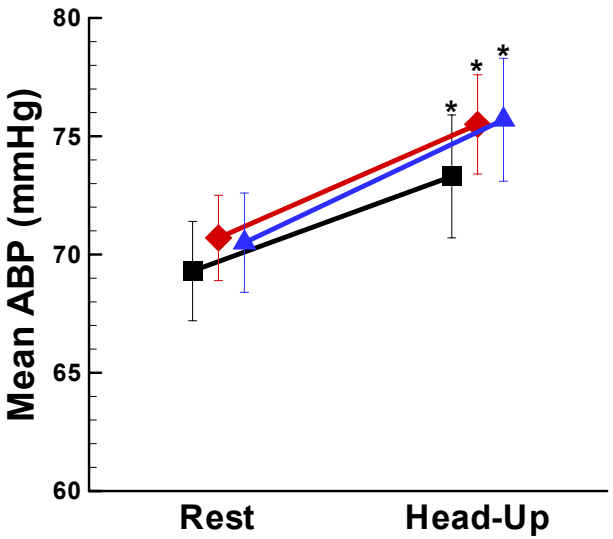
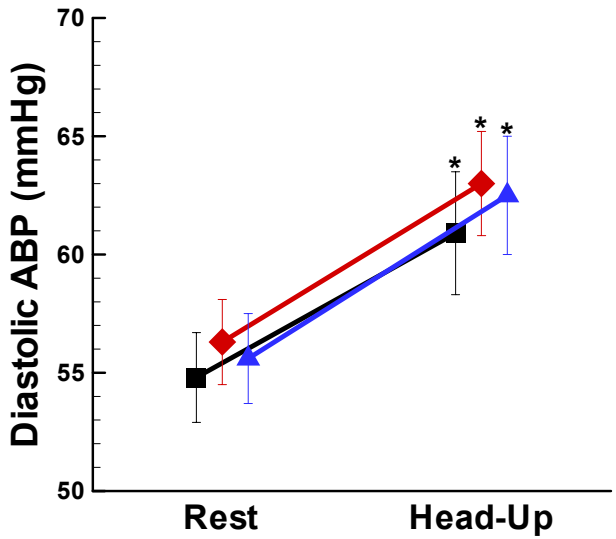
: mean ± SE

N = 20









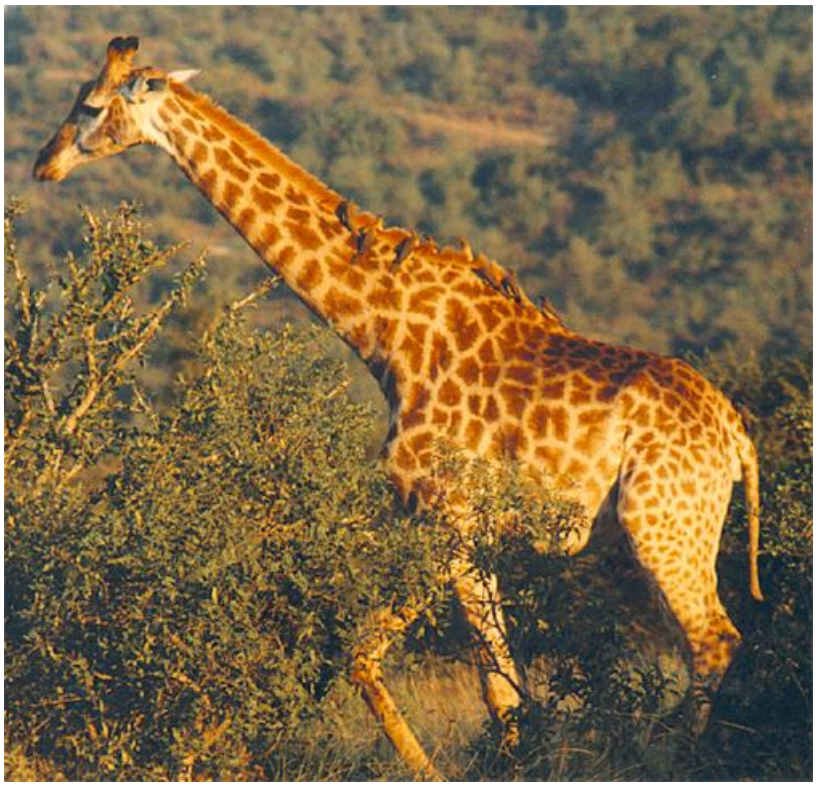
# P < 0.05

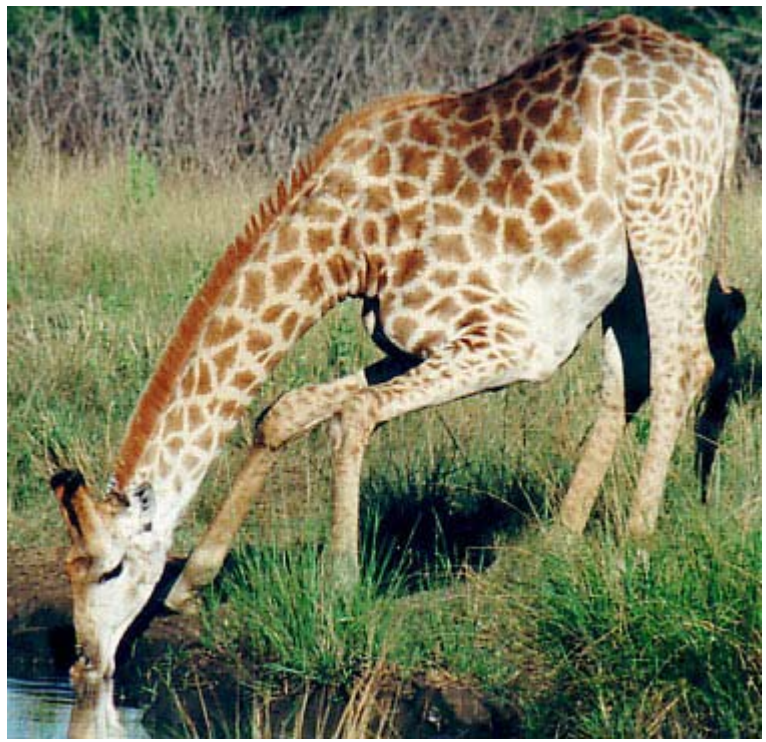
* P < 0.005
HU vs Rest

Conclusions

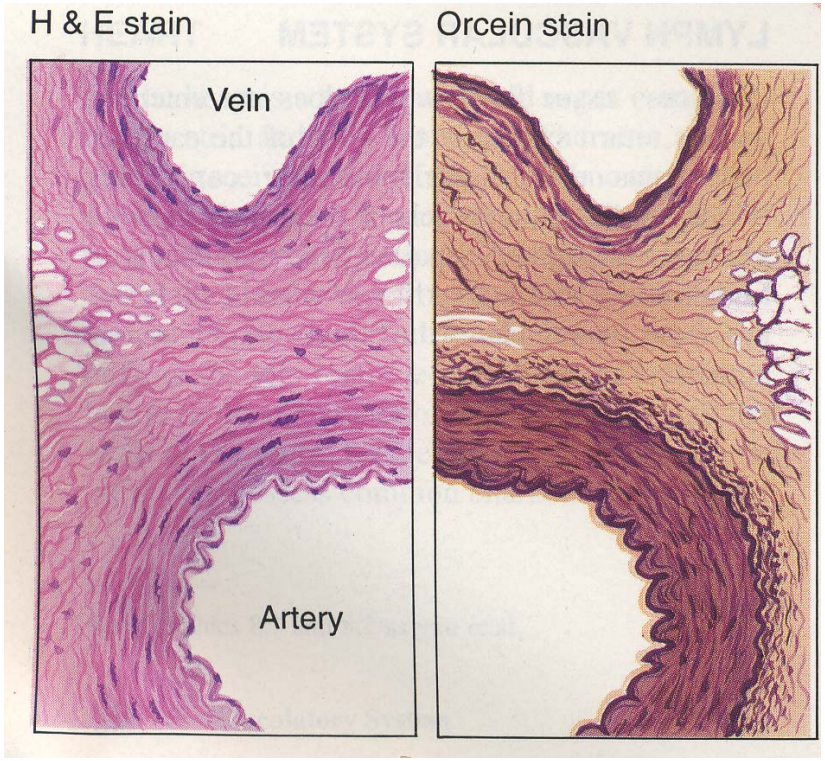
- Several cardiovascular control mechanisms allow for short term and rapid adaptation to gravitational stress.
- In the intact, controlled circulation, mean arterial blood pressure at the level of the heart rises when standing up.
- Longer term adaptation (endocrine, fluid balance) also play important roles.

What about the Giraffe?

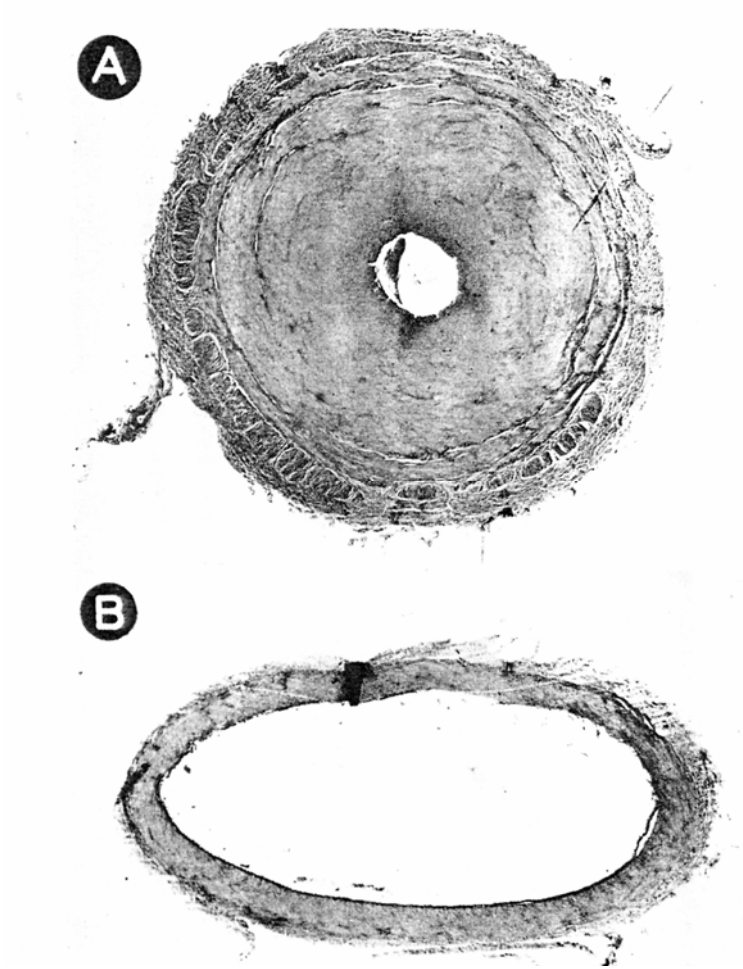




Venous Pooling?



Gartner, Hiatt. Coloratlas of Histology, 1994.



Goetz et al. Angiology. 1957; 8(6):542

Venous Pooling?

… Giraffes come with their own anti-g suits:

Thick skin and tight fascia (connective tissue) surround dependent blood vessels. Leg veins and lymphatics have one-way valves to reduce venous pooling and allow muscle pumping.