6. Thermoregulation in poikilotherms and homotherms

BIOS 0501B (Group A)
DBS, PU, Sem 5; 2015

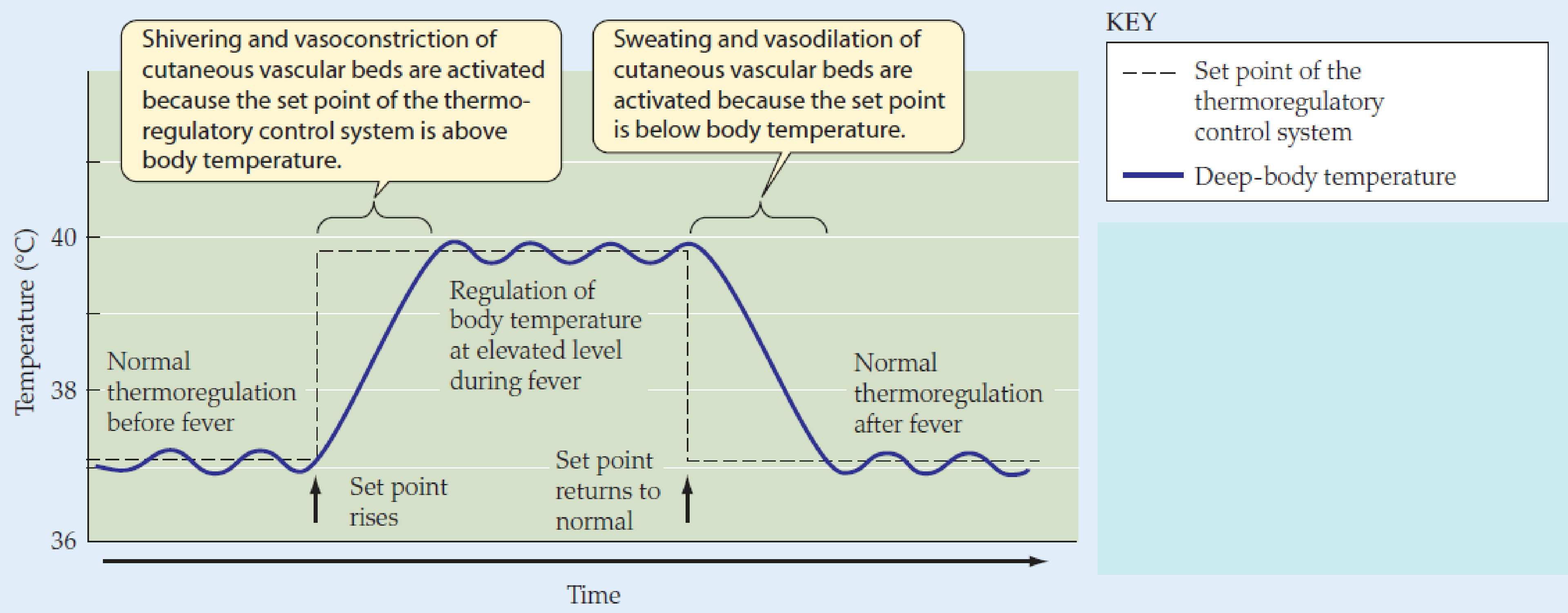
Homeothermy

- Regulating body temperature using metabolic heat
- This gives independence from external thermal condition to the organism at a cost
- First they need to figure out what is outside temperature
- Then, what is inside
- That will tell the body either to raise the temperature
- Or lower the temperature
- And keep at it

- It is a complex behavioral and metabolic balance

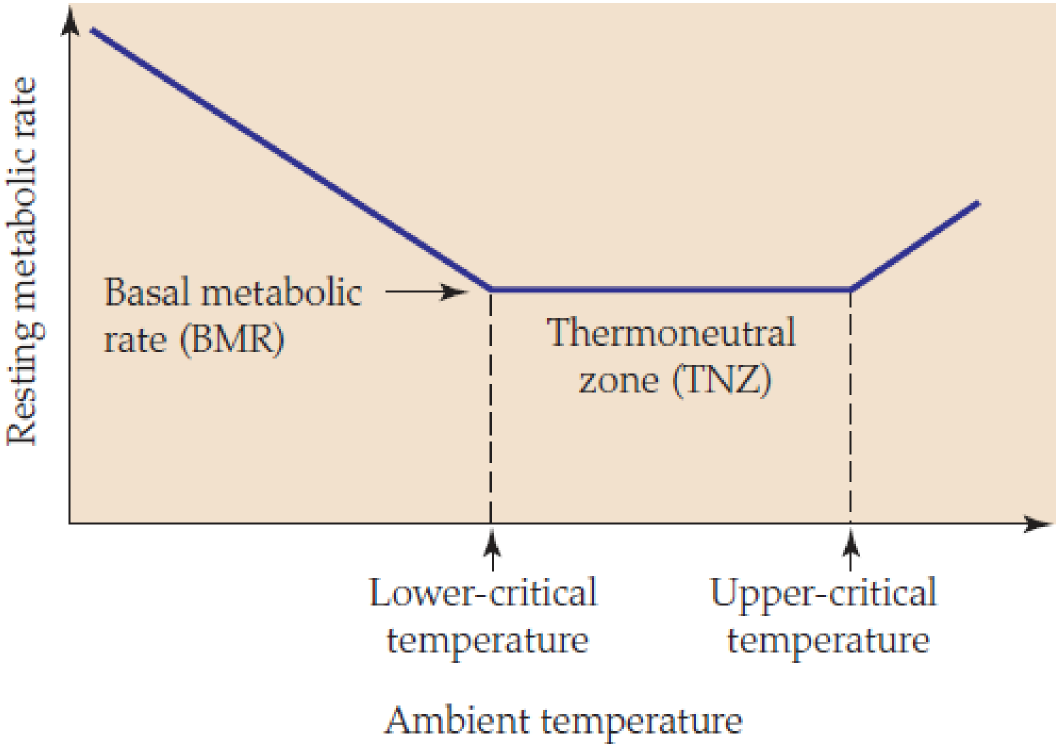
The way control works

- It has ‘sensors’, a ‘set point’ and a ‘controller’
- It works in ‘negative feedback loop’
- A ‘fever’ is resetting the thermostat to a different ‘set point’

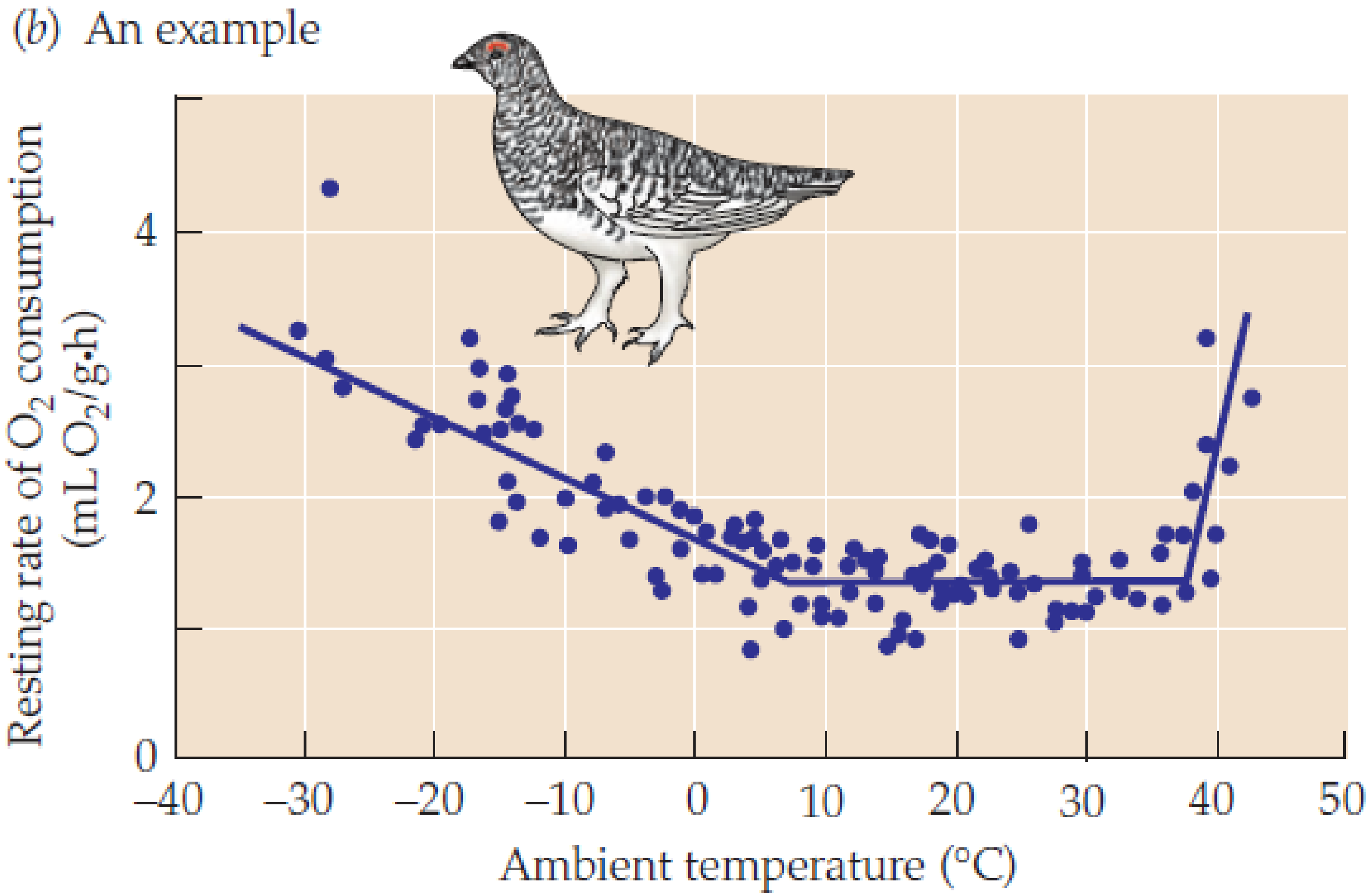


Basics

- BMR keeps you at TNZ (Thermo Neutral Zone)
- Lower and/or higher than TNZ will increase metabolic rate



Example


(b) An example
Resting rate of O_2 consumption ($mL\ O_2/g \cdot h$)
0
2
4
−40
−30
−20
−10
0
10
20
30
40
50
Ambient temperature (°C)

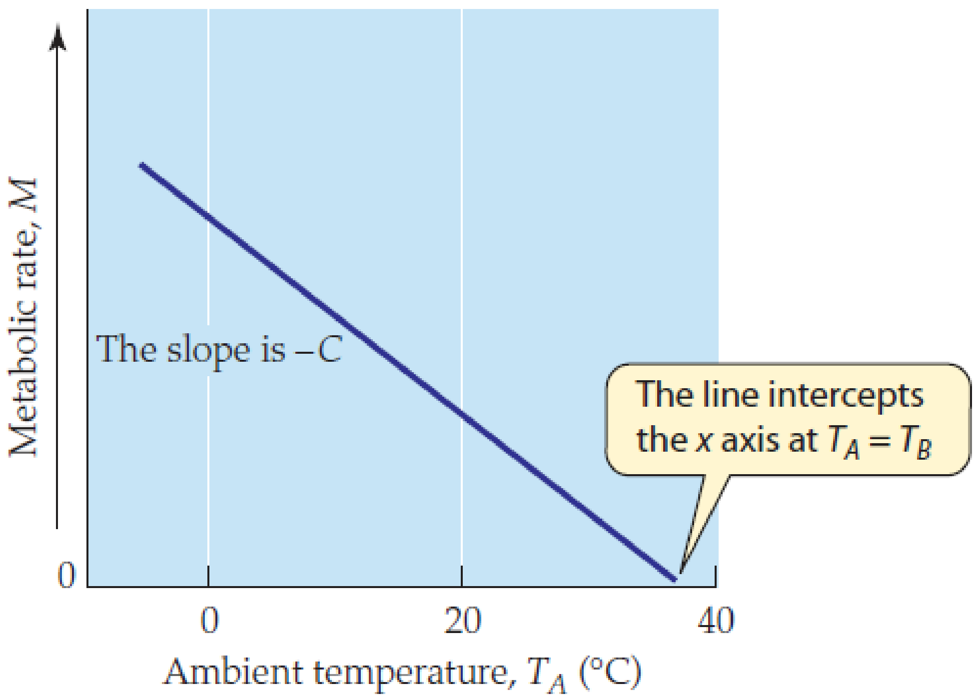
The explanation

- The rate of heat transfer is $\propto$ Temperature of body (T_B) – Temperature of environment (T_A)
- In a constant environment this is called Dry heat transfer
  - Dry heat transfer $\propto T_B - T_A$
- Below TNZ (when evaporation is not much of a factor)
  - Metabolic rate [M] = Constant [C] ($T_B - T_A$)
  - Linear heat transfer equation
  - So an animal with high C has to have a higher M and vice versa
  - Conversely M = 1/I ($T_B - T_A$); I= Insulation
  - So an animal with better insulation will need less metabolic heat
  - If you can modulate I, then you can keep M constant

Temperatures below Thermoneutrality

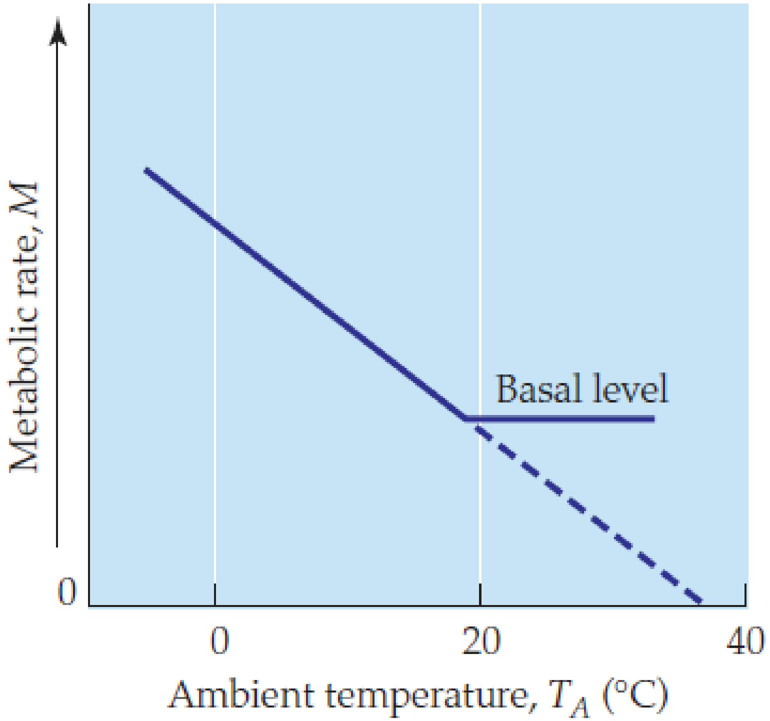
- The lower critical temperature is when I is max
- Below that temperature I constant (because it stays at max)
- Therefore C is constant
- And in that condition if the animal wants to keep T_B constant
- Then variables are
  - M
  - T_A
- So, < T_A = > M
- Plotting M as a function of T_A

(a) $M = C(T_B - T_A)$ with C and T_B constant ($T_B = 37°C$)



In actuality

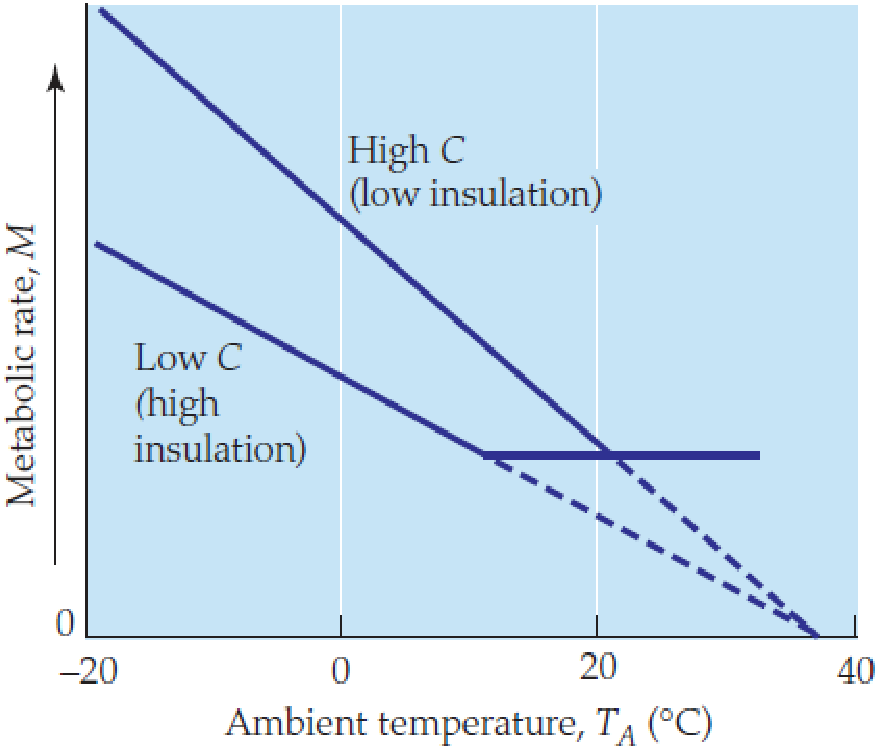
(*b*) The plot from (*a*), recognizing that *M* actually falls only to the basal level



Comparison

Between animals with high vs low insulation

(*c*) Comparison of two animals that differ in *C* below thermoneutrality

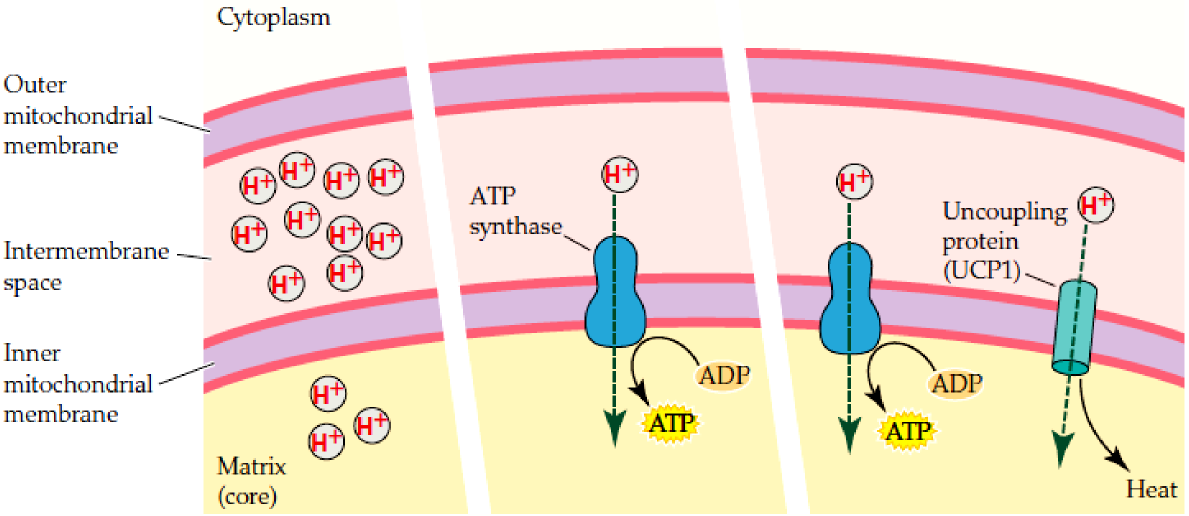


Thermogenic mechanisms

- At temperatures below the TNZ endotherms use two mechanisms to increase heat production
  - Shivering: unsynchronized contraction and relaxation of skeletal-muscle motor units in high-frequency rhythms, mediated by motor neurons (nerve cells) of the somatic nervous system
  - Nonshivering thermogenesis (NST): an acclimated endotherm at lower temperatures stops shivering. Most prominent mechanism is using brown adipose tissue (BAT), also called brown fat
    - But only limited to placental mammals
      - (1) cold-acclimated or winter acclimatized adults (particularly in species of small to moderate body size), (2) hibernators, and (3) newborn individuals
  - Regional heterothermy:

BAT

- This is a specialized type of adipose tissue—often reddish brown
- BAT receive a rich supply of blood vessels and are well innervated by the sympathetic nervous system
- Sympathetic nervous system releases norepinephrine
- BAT increases oxidation = more heat



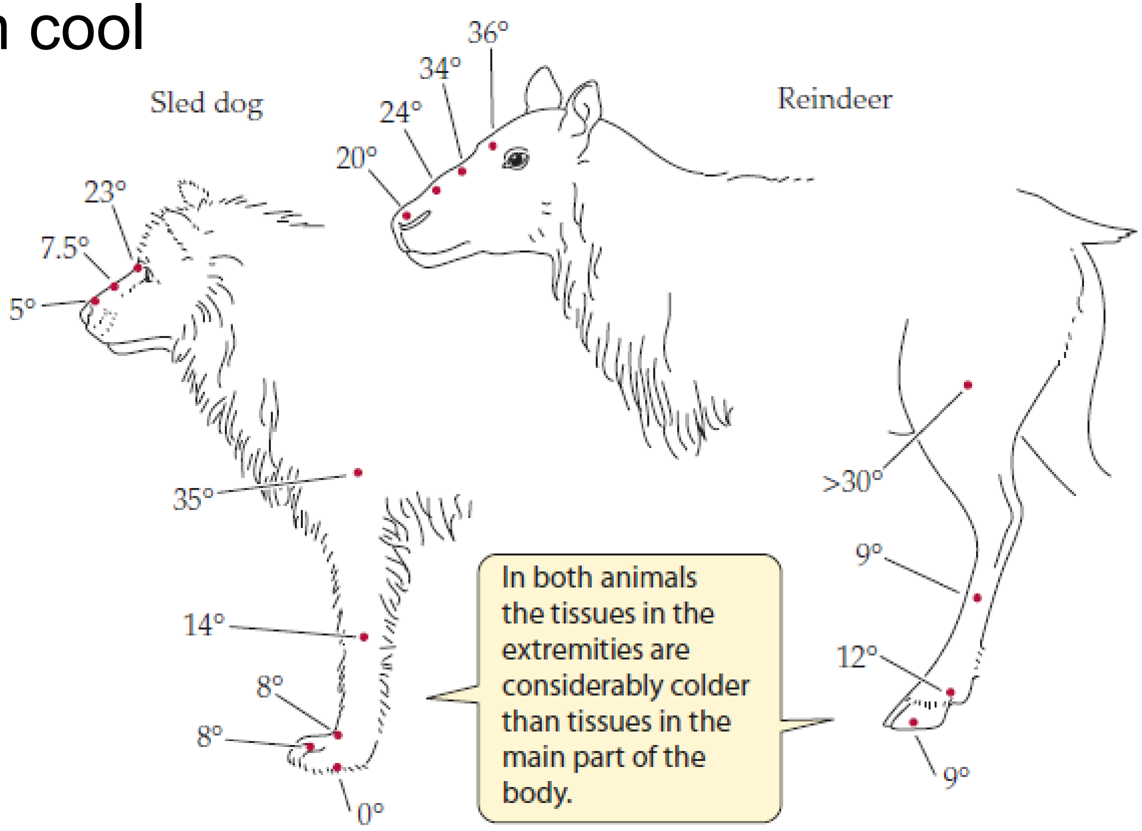
(*a*) The proton electrochemical gradient produced by electron transport: an energy store

(*b*) Back-diffusion of protons via ATP synthase, providing energy for synthesis of ATP: the mechanism of oxidative phosphorylation

(*c*) Back-diffusion of protons in a specialized cell with UCP1: the mechanism of uncoupling

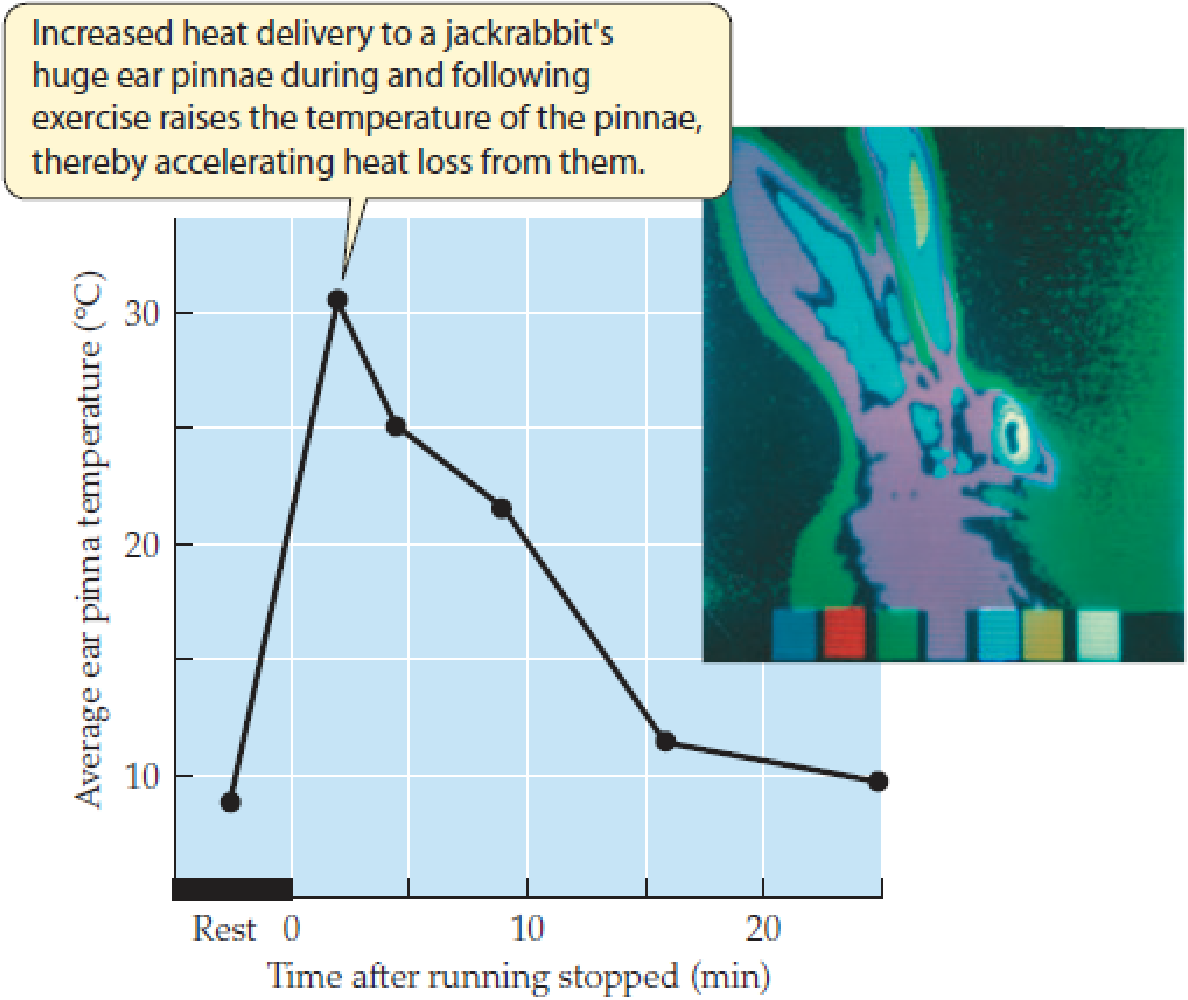
Regional heterothermy

- Below TNZ appendages are potentially major sites of heat loss because they have a great deal of surface area relative to their sizes, are often thinly covered with fur or feathers, and exhibit (because of their dimensions) intrinsically high rates of convective heat exchange
- So endotherms let them cool



In both animals the tissues in the extremities are considerably colder than tissues in the main part of the body.

Same organs: different use

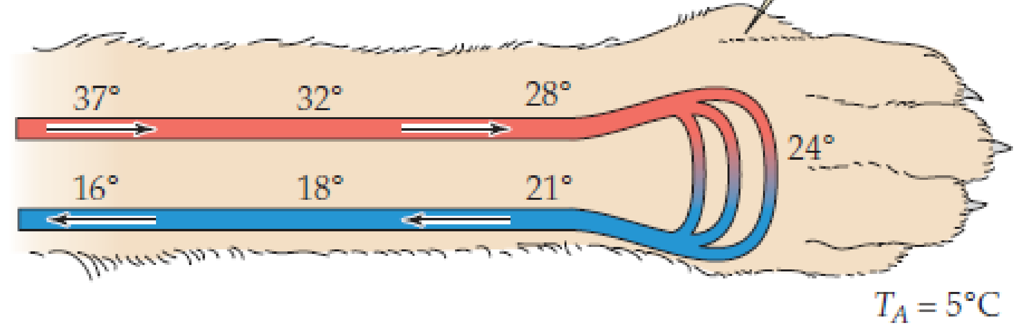


Increased heat delivery to a jackrabbit's huge ear pinnae during and following exercise raises the temperature of the pinnae, thereby accelerating heat loss from them.

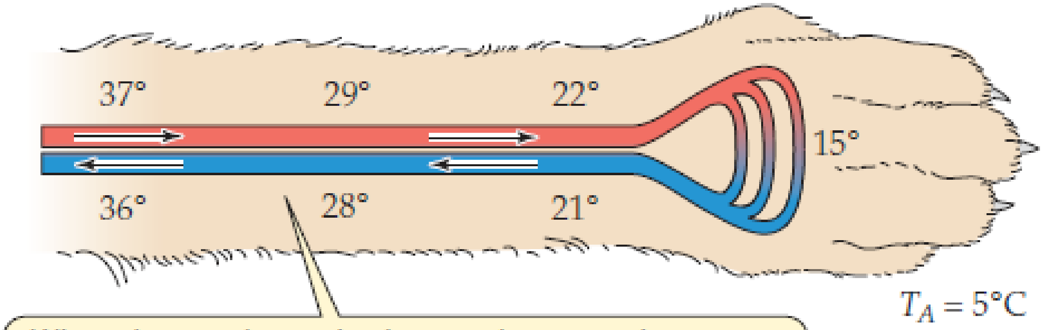
Countercurrent heat exchange

With this arrangement of blood vessels, blood loses heat steadily to the environment as it flows in and out of the limb, and the temperature of the blood steadily declines.

(*a*) Blood flow without countercurrent heat exchange



(*b*) Blood flow with countercurrent heat exchange



When the arteries and veins are close together, allowing countercurrent heat exchange to occur, some of the heat lost from the arterial blood enters the venous blood. The temperature of the venous blood thus rises as the blood travels toward the body.

Temperatures above Thermoneutrality

- Behavioral mechanisms
- Hyperthermia
  - Increasing T_B will prevent heat gain
  - And also good for less water loss
- Evaporative cooling
  - Sweating
  - Panting
  - Gular fluttering

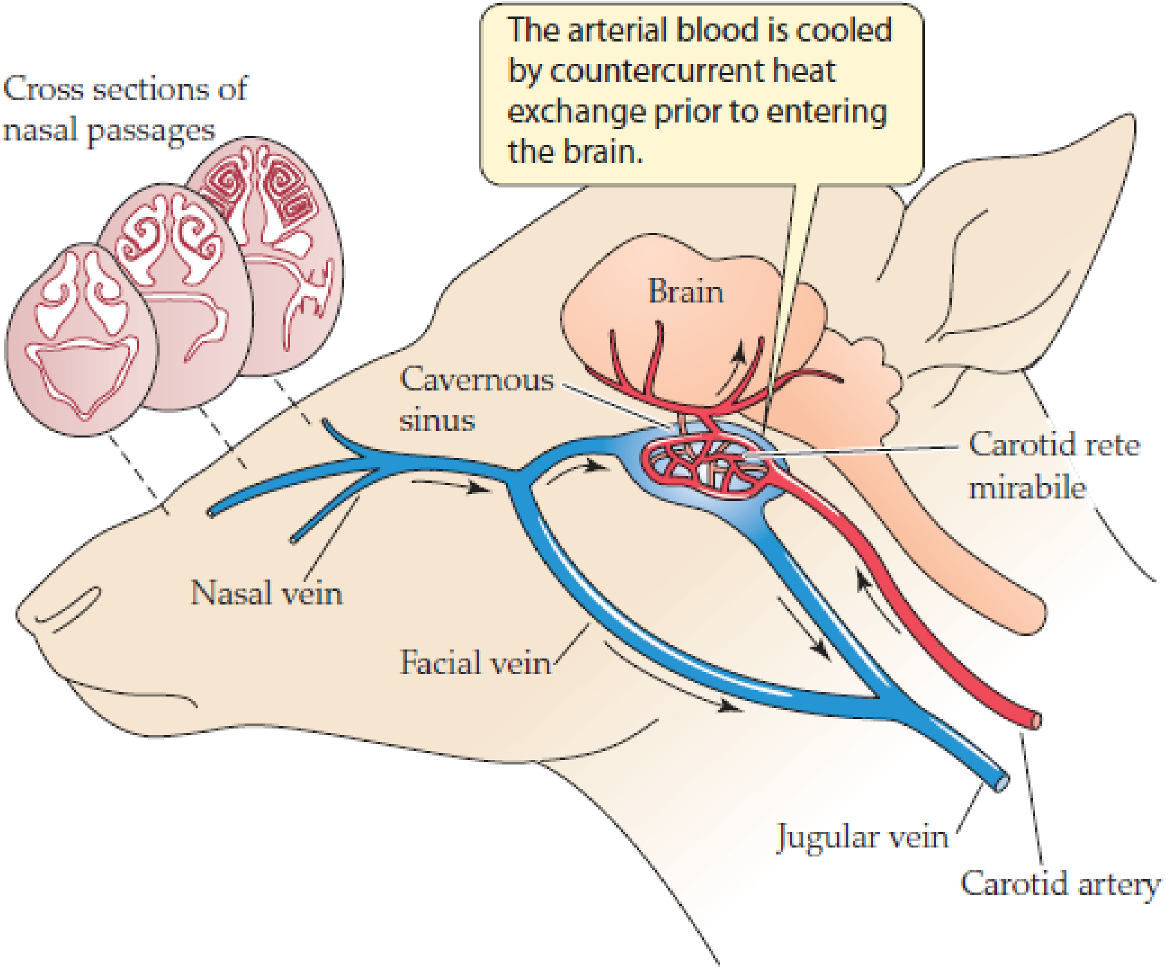
Cycling body temperature

- A dehydrated dromedary (Arabian camel) in summer permits its deep-body temperature to fall to 34–35°C overnight and then increase to more than 40°C during each day. Its body temperature therefore cycles up and down by about 6°C. The advantage of such cycling is that it permits some of the heat that enters the body during the intensely hot part of each day to be temporarily *stored in the body* and later voided by nonevaporative rather than evaporative means.
  - Save water while maintain temperature

Hyperthermia

- Birds commonly permit their body temperatures to rise to profoundly high levels when in hot environments; whereas resting birds typically have body temperatures near 39°C in the absence of heat stress, they commonly have body temperatures as high as 43–46°C in hot environments.
- Among mammals, ertain antelopes native to the deserts and dry savannas of Africa provide the extreme examples. Two such species, the beisa oryx (*Oryx beisa*) and Grant’s gazelle (*Gazella granti*), sometimes permit their rectal temperatures to reach 45.5–47°C (114–116°F) without ill effect.

With a cool brain



The arterial blood is cooled by countercurrent heat exchange prior to entering the brain.

Finally: evaporative cooling

- Sweating: Sweating increases the rate of cutaneous evaporation by a factor of 50 or more by wetting the outer surface of the skin. Humans working strenuously in the desert, for example, can attain sweating rates of 2 L/h. On the other hand, Rodents, rabbits, and hares lack integumentary sweat glands. Mammals only.
- Panting: Panting increases the rate of evaporative cooling because water evaporates from the warm, moist membranes lining the respiratory tract into the air that is breathed in and out. Birds and mammals.
  - Panting too much remove CO_2 faster than they are made, so the blood becomes basic.
- Gular fluttering: Similar to panting. Birds rapidly vibrate their gular area (the floor of the buccal cavity).

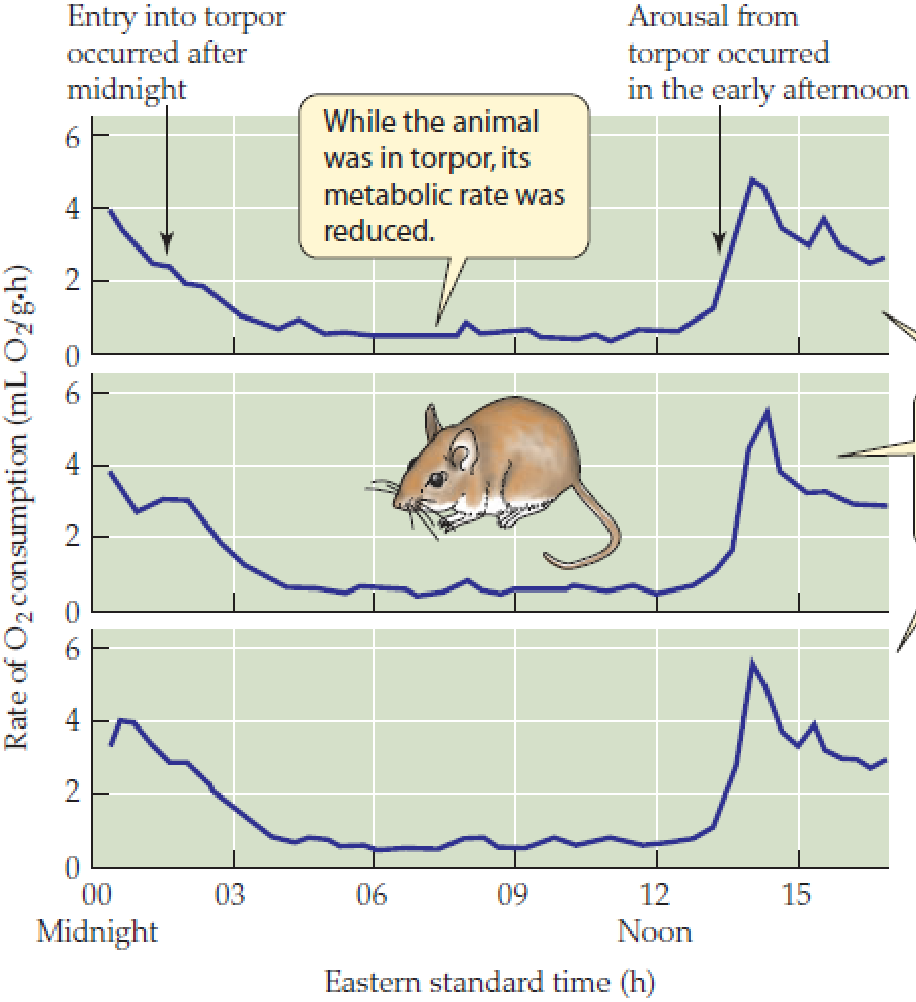
Endothermy is expensive

- In a controlled environment
  - Temp @ 37
- Two equally weighed animals
  - One endo and one ecto thermic
- At resting metabolic phase
  - BMR & SMR
- The endothermic animal uses 4-10 times more energy than the ectotherm
- In colder ambient temperatures endotherm spend more energy to main the temperature while ectotherm let it fall
  - So in those conditions endotherms spends more than 4-10 times
- Average field metabolic rate is typically 12–20 times higher in mammals and birds than in lizards or other nonavian reptiles of the same body size

Escaping endothermy

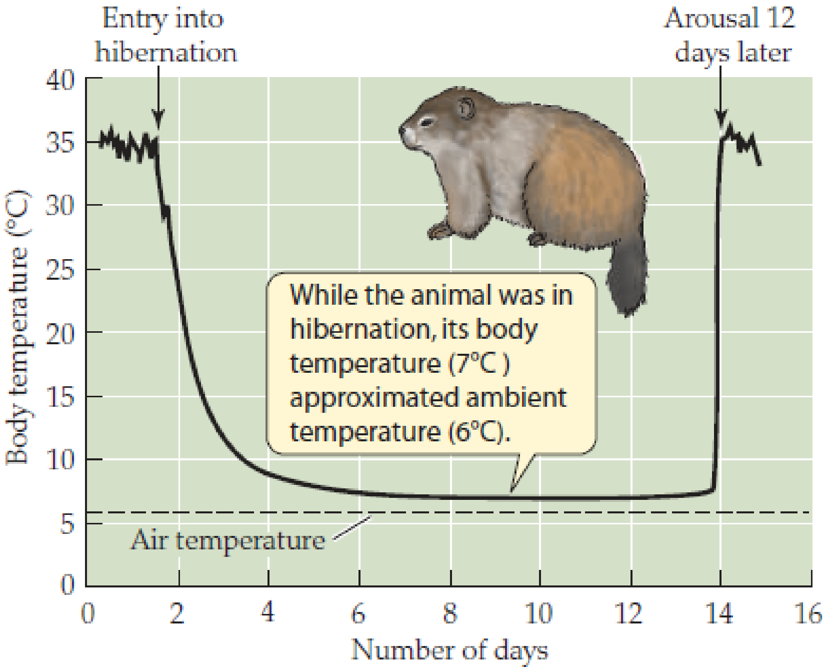
- Controlled hypothermia is a general term for this sort of phenomenon; hypothermia is the state of having an unusually low body temperature, and in the cases we are discussing, it is “controlled” because the animals orchestrate their entry into and exit from hypothermia rather than being forced.
  - these are all states in which an animal *allows its body temperature to approximate ambient temperature within a species-specific range of ambient temperatures*
- When an animal allows its body temperature to fall close to ambient temperature for periods of several days or longer during winter, the process is termed *hibernation*. When this occurs during summer, it is called *estivation*.
- Same thing for only part of each day (generally on many consecutive days), the process is termed *daily torpor* in any season

Examples



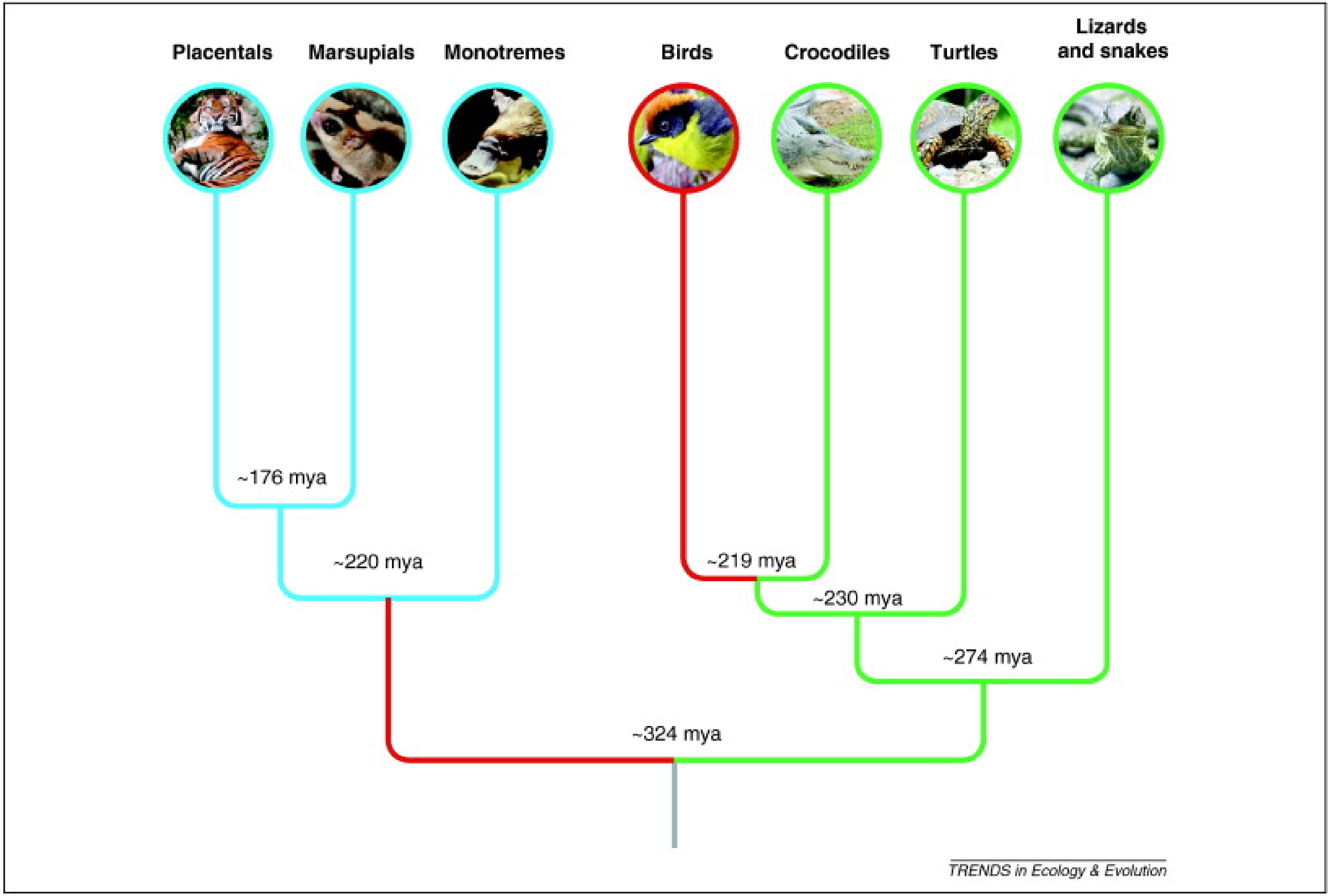
While the animal was in torpor, its metabolic rate was reduced.

The three panels depict three consecutive days, from top to bottom.



While the animal was in hibernation, its body temperature (7°C) approximated ambient temperature (6°C).

Origin of endothermy

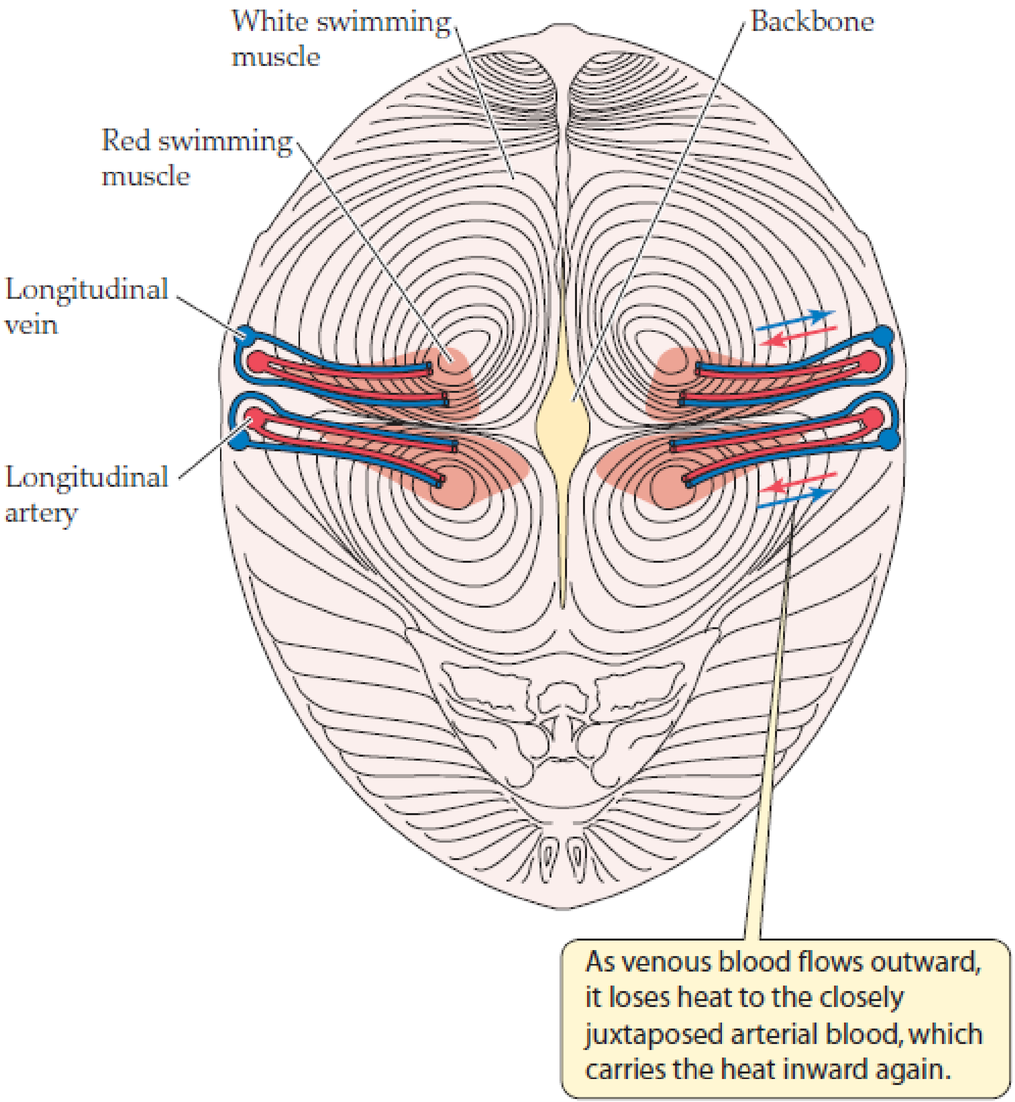


"Trends in Ecology & Evolution" Volume 26, Issue 8, August 2011, Pages 414–423

Warm blooded fish

Some fishes like tunas, lamnid sharks, and billfishes, temperatures within *certain body regions* exceed water temperature, sometimes substantially

They not only raise their metabolic heat using their muscles but also prevents heat loss using countercurrent blood vessels



As venous blood flows outward, it loses heat to the closely juxtaposed arterial blood, which carries the heat inward again.

Text and image

Hill

almost