Thermal Strategies: Chapter 10

1. Two main types
   A. Tolerance
   B. Regulation
2. Both strategies have costs and benefits
3. Do not use “warm-blooded” and “cold-blooded” to describe strategies.

Terminology

1. Thermal Strategies
   A. Endothermy
   B. Homeothermy
   C. Heterothermy
   D. Poikilothermy or Ectothermy
2. Temperature
   A. Average kinetic energy of a system
   B. Most important aspect of the physical environment for life
3. Heat
   A. Temperature depends on the amount of heat contained per unit mass tissue

Overview of Thermal Physiology

1. Thermal energy
   A. influences chemical interactions
2. Thermal strategy
   A. responses that regulate that body temperature
3. Ambient temperature
4. Surviving thermal extremes and change
5. spatial and temporal variation

Physics of heat transfer

1. Heat loss = Heat gain
2. Figure 10.3 An animal exchanges heat with its environment
   A. Conduction
   B. Convection
   C. Evaporation
   D. Radiation
1. Conduction
   A. transfer of heat between 2 bodies in direct contact
2. Convection
   A. Transfer of heat to an external fluid that is moving
   B. Conduction rate is increased by convection
3. Evaporation
   A. Water molecules absorb thermal energy
4. Radiation
   A. Emission of electromagnetic radiation
   B. Basking
   C. Animals lose thermal energy when they emit radiant heat
1. **Physiological Regulation**
   A. Redirect blood flow for increased heat gain-heat loss
   B. Vasodilation and vasoconstriction
   C. Figure 10.5 An antelope jackrabbit

2. **Behavioral Thermoregulation**
   A. Reposition body relative to heat sources
   B. Figure 10.8 Behavioral thermoregulation documented by comparison of real lizards with inanimate lizard models

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### Effects of Temperature Change

1. Metabolic reactions and metabolic rates vary with temperature.
2. Temperature increases accelerate most physiological processes.
3. A temperature increase of 10°C typically increases the rate of O₂ consumption 2-3-fold.

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1. **Thermal Strategies**
   A. Stenothermal
   B. Eurythermal

2. **Effects of Body Temperature Change**
   A. Temperature affects the rate of chemical reactions needed to maintain homeostasis
   B. Too low: metabolism not fast enough to maintain homeostasis
   C. Too high: reactions in metabolic pathways uncouple, enzymes denature, etc.

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1. **Acute Response**
   1. \( Q_{10} = \frac{V_{\text{reaction}}(T + 10^\circ)}{V_{\text{reaction}}(T)} \)

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1. Figure 10.10 The relation between metabolic rate and body temperature in tiger moth caterpillars plotted in two ways
2. Acute Response

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1. Acute response (\(Q_{10}\))
2. Metabolic compensation (Chronic response)
Fig. 10.12: Gene Expression: The physiological basis of thermal compensation (acclimation)

1. Acclimation is due to a change in the number and activities of enzymes involved in metabolism.
2. In response to increased temperature, expression of metabolic enzymes is decreased, partially compensating for the increase in reaction velocity per enzyme.
3. Similarly, mitochondrial numbers are decreased in response to increased temperature.

Thermal Adaptation

1. Different species have evolved different varieties of enzymes for different environments.
2. Maximum substrate affinity at different temperatures (Fig. 10.20)

Strategies for Surviving Freezing Temperatures

1. Deleterious effects of ice crystal formation
   A. Ice crystal formation
   B. Supercooling
2. Freeze-avoidance
   A.
3. Freeze-tolerance
   A.

Freeze Avoidance

1. Solutes in general depress the freezing point of a liquid (Supercooling)
2. Antifreeze macromolecules
   A. Freezing point depression
   B. Figure 10.24 Barnacles encased in ice during low tide along a northern seacoast
   C. Figure 10.26 Seasonal changes in antifreeze protection in winter flounder (*Pleuronectes americanus*)

Freeze Tolerance

1. Cryoprotectants
   A. Substances that help animals avoid damage from freezing of body tissues
2. Many freeze tolerant organisms have ice-nucleating agents
   A. Figure 10.25 The process of extracellular freezing in a tissue
   B. Wood frog, *Rana sylvatica* figure 10.27
Figure 10.28: The relation between resting metabolic rate and ambient temperature in mammals and birds

**Thermal Zones**

1. Mammals and Birds modify conductance, etc. in the Thermal Neutral Zone to alter heat loss.
2. Upper critical temperature
3. Lower critical temperature
4. Below the TNZ
   - metabolic heat production
   - metabolic rate increases linearly with decreasing temperature

**Fig. 10.29c: Comparison between two animals that differ in C below thermoneutrality**

1. Conductance (C) is inversely proportional to insulation (I)
2. \( M = 1/I \) (Tb – Ta)
3. In TNZ, balance between I and Tb-Ta
4. Below LCT, animal needs to generate heat to match heat loss, increase MR

**TEMPERATURES ABOVE THERMONEUTRALITY**

1. Keeping Cool:
   A. Evaporation
   B. Sweating – humans, camels, antelope, cattle.
   C. Panting – carnivores, sheep, goats.
   D. Saliva spreading by licking
      - many marsupials & some rodents.
   E. Gular Flutter in birds
      - vibration of upper throat & floor of mouth.

**Maintaining a Constant Body Temperature**

1. Endothermy requires high metabolic rate
2. Two components
   A. Mechanisms to retain heat
      - Modulating Insulation
        - Piloerection
        - Postural Responses
        - Vasomotor Response
          - Altering blood flow to the body surface
   B. Ability to produce heat (thermogenesis)
Thermogenesis
1. Heat is a by-product of metabolic processes
   A. Energy metabolism
   B. Digestion
   C. Muscle activity
2. Both endotherms and ectotherms generate heat
3. Endotherms retain enough heat to elevate body temperature above environmental temperature

Thermogenesis
1. Shivering Thermogenesis
   A. Unique to birds and mammals
   B. Uncoordinated myofiber contraction
2. Nonshivering Thermogenesis
   A. Brown Adipose Tissue (BAT)
      a. Differs from white adipocytes
      b. Higher levels of mitochondria
      c. Produce thermogenin
   B. Figure 10.31 The deposits of brown adipose tissue in newborn rabbits

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**Figure 10.32** Regional heterothermy in Alaskan mammals

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1. Figure 10.33 A thermal map of an opossum showing regional heterothermy in the pinna of the ear (black). The surface of the ear was close to ambient (10°C)
2. Heat loss across appendages is sometimes modulated in ways that aid thermoregulation
   A. Jackrabbit ears (Figure 10.34)

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**Figure 10.35** Blood flow with and without countercurrent heat exchange

**Figure 10.36** Countercurrent heat exchange short-circuits the flow of heat in an appendage

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**Figure 10.37** Structures hypothesized to be responsible for cooling the brain in artiodactyls
Temporal heterotherms

1. Undergo prolonged changes in body temperature
   A. Hibernation: body temperature, heart rate and metabolic rate drop
   B. Aestivation: inactivity during summer months
   C. Daily Torpor

Thermal adaptation: Hibernation

1. Induced by duration of light associated with time of year which influences hormonal cycles.
2. Many mammals build up fat stores before hibernating.
3. White fat is used primarily to feed the animal during hibernation
4. Brown fat is used for arousal. (non-shivering thermogenesis)
Fish that are Regional Heterotherms

1. Retain heat in specific regions of the body
2. The heat exchanger (rete mirabile).
3. Cross section of a tuna showing nature of blood supply to red swimming muscles (Fig. 10.45)

Heat Production in Insects Prior to Flight

1. Three mechanisms
   A. Carbohydrate metabolism within flight muscles
   B. Antagonistic flight muscles contract simultaneously
   C. Wing movement

Some insects are part-time endotherms

1. During cool temperatures (0-10°C) some bees and moths can warm their tissues
2. At 37°C they are able to fly.
3. A counter current heat exchanger retains heat in the thorax and abdomen.