Lecture 30, 06 December 2005

Metabolism (Chapter 5-7), Thermal Physiology (Ch 8-9)
Miscellaneous, Wrap-Up, Last Lecture, Oral Presentations

Vertebrate Physiology
ECOL 437 (aka MCB 437, VetSci 437)
University of Arizona
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1. Metabolism
2. Thermal Physiology
3. Etc.

Text:
(skim 5-7)
(skim 8+9)

- Oral Presentations
  (PPT files to KEB)
  (most on 07 Dec, four on 06 Dec in lecture)
- Wrap-Up
Metabolism

- Chemical reactions in the body
- Temperature dependent rates
- Not 100% efficient, energy lost as heat
  (not ‘lost’ if used to maintain Tb)

1. **Anabolic**
   - creation, assembly, repair, growth
   (positive nitrogen balance)

2. **Catabolic**
   - energy release from complex molecules
     (carbos, fats, proteins)
   - energy storage in phosphate bonds (ATP) and metabolic intermediates (glucose, lactate)
Chemical Energy

Metabolic Rate

- measurable conversion of chemical energy into heat

-used to understand:
- energy budgets
- dietary needs
- body size implications
- habitat effects
- costs of various activities
- mode of locomotion
- cost of reproduction
Metabolic Rates

- **Basal Metabolic Rate**, BMR
  - minimal environmental and physiological stress (appropriate ambient temperature, post-digestive, resting etc.)

- **Standard Metabolic Rate**, SMR
  - similar to BMR, but at a given Tb

- **Field Metabolic Rate**, FMR
  - average metabolic rate of animal in natural setting
  - hard to measure

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Metabolic Rates

**Basal Metabolic Rate**, BMR
- important components:

1. Membrane form and function
   - maintenance of electrochemical gradients
   - proton pumps in mitochondrial membranes
   - Na/K-ATPase pumps in plasma membrane

2. **Protein** synthesis

3. **ATP** formation
Oxygen Debt
- repay anaerobic contribution to elevated metabolism
- oxidize anaerobic products (e.g., lactate)

VO₂ Measurement - Before, during, and after exercise

Desert Iguana

Thomas Hancock: data and slides
Activity and Associated Oxygen Consumption

EEOC: Excess Exercise Oxygen Consumption

EPOC: Excess Post-exercise Oxygen Consumption

EEOC = Excess Exercise Oxygen Consumption
EPOC = Excess Post-exercise Oxygen Consumption

TEOC = Total Excess Oxygen Consumption
= EEOC + EPOC

Activity and Associated Oxygen Consumption
Energy Budget Implications

Costs for Exercise and Recovery:
- A Single Bout: 15 seconds at Maximum intensity

- Traditional Estimates:
  0.7% of daily energy expenditure

- Inclusion of EPOC:
  4.6% of daily energy expenditure
Length of Bout is Important:

![Graph showing VO2 over time with a highlighted section for bout duration.](attachment:image.png)
EPOC is now a large fraction of the net metabolic expenditure.

Phylogenetic Effects

<table>
<thead>
<tr>
<th>FMR (kJ/day)</th>
<th>100g reptile</th>
<th>142</th>
</tr>
</thead>
<tbody>
<tr>
<td>100g mammal</td>
<td>11.8</td>
<td></td>
</tr>
<tr>
<td>100g bird</td>
<td>242</td>
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</tbody>
</table>

(Nagy, Girard, Brown 1999)

Energy Budgets...
Ecological Role...
Scaling Effects

**Allometry** - changes in body proportions as animals get larger (mouse vs. elephant)

**Metabolic Rate** - mass-specific metabolic rate decreases with increasing body mass

(a) = elephant freaked out and died (1960’s) in a study of ‘musth’ [elephantine fallacy]

-What is the correct dose?
-Importance of Scaling!
\[
\text{MR} = aM^b
\]

\[
\log \text{MR} = \log a + b(\log M)
\]

\(b = 0.75\) (slope)
Hemoglobin dissociation curves and body size

Figure 58. Dissociation curves of oxyhemoglobin from a number of mammals show that the blood of smaller mammals will unload oxygen under a higher oxygen pressure than that of larger mammals. This helps in the delivery of sufficient oxygen to the tissues to maintain the high metabolic rates of small animals. The dashed curve (8B) indicates the effect of acid (Bohr effect) on mouse blood (curve 8). (Data from Schmidt-Nielsen and Larimer, 1958. Elephant from Barich et al. 1963.) Knud Schmidt-Nielsen 1972
Bohr effect and body size

Figure 53. The effect of acid on the unloading of oxygen from the blood (Bohr effect, expressed as $\Delta \log P_{O_2}/\Delta pH$) is greater in small than in large animals. (Data from Riggs, 1960.)

Knut Schmidt-Nielsen 1972

Capillary density and body size

Figure 54. Capillary density in the gastrocnemius muscle. In very small mammals the capillary counts are high, but for a body size of a rat or larger there seems to be no clear trend in relation to body size. (Data from Schmidt-Nielsen and Pennycuik, 1951.)

Knut Schmidt-Nielsen 1972
\[ \log \text{M}_{\text{skeleton}} = \log a + b(\log \text{M}) \]

Isometry is rare

\( b = 1.13 \)

(slope)

Figure 47. Weight of the skeleton of mammals increases more than proportionally to an increase in body weight. The slope of the regression line is 1.13. (Data from Kayser and Heusner, 1964.)

Thermal Neutral Zone
Thermal Neutral Zone

**Within TNZ:**
- Vasomotor
- Posture
- Insulation
  - fluff fur/feathers

**Below TNZ:**
- Increase metabolism above basal

**Above TNZ:**
- Cool via evaporation

Thermoregulation

**Cardiovascular control of heating and cooling**

- Cardiac Shunts
- Peripheral Vasodilation
Pyrogens

Fever

Dipsosaurus dorsalis

Endotherms in the COLD...

Countercurrent Heat Exchange

Figure 8.9  Countercurrent heat exchange. (A) A diagram representing the circulation in a limb of a mammal showing hypothetical temperature changes of the blood in the absence (a) and presence (b) of countercurrent heat exchange. Arrows indicate direction of blood flow. In (b), the venous blood warms up heat (thus cooling the arterial blood) as it flows along a path of which because even as it becomes warmer and warmer. It ideally encounters arterial blood that is warmer yet. (B) Regulation of external body temperature in the camel. Temperature regulation is accomplished in part by countercurrent heat exchange. An intricate mechanism of veins and arteries acts to keep the temperature of the body near that of the environment to keep it is hot from the body.

Hot Body, Cool Brain

Keep brain cool during prolonged increased organismal activity:

- Countercurrent
- Carotid Rete

Knut Schmidt-Nielsen 1997
Much more difficult for water breathing animals to maintain body temperatures above ambient because rate of heat transfer is greater than rate of O₂ transfer in water (high specific heat)

Thank you all for working hard to learn physiology this semester.

Kristen and I have very much enjoyed working with you all.

I would like to thank Kristen for being an exceptional TA, an outstanding colleague, and a talented scientist and educator.
Oral Presentations:

Tom
Amir
Shahin
Brooke