Goals:

➢ To appreciate that different tissues have very different metabolic rates
➢ To understand basic physiological correlates of large vs. small animals and of endotherms vs. ectotherms

I. Do all tissues (within an individual) have the same metabolic rate?

A. No, rates of metabolism differ strikingly among tissues. Internal organs don’t occupy much of total mass, but do use most of energy. For a human at rest:

<table>
<thead>
<tr>
<th>Organ</th>
<th>% total mass</th>
<th>% total E</th>
</tr>
</thead>
<tbody>
<tr>
<td>kidney</td>
<td>0.45</td>
<td>7.7</td>
</tr>
<tr>
<td>heart</td>
<td>0.45</td>
<td>10.0</td>
</tr>
<tr>
<td>brain</td>
<td>2.1</td>
<td>16.0</td>
</tr>
<tr>
<td>abdom. organs (except kidney)</td>
<td>3.8</td>
<td>33.6</td>
</tr>
<tr>
<td>lungs</td>
<td>0.9</td>
<td>4.4</td>
</tr>
<tr>
<td>muscle</td>
<td>41.5</td>
<td>15.7</td>
</tr>
<tr>
<td>other</td>
<td>50.7</td>
<td>11.9</td>
</tr>
</tbody>
</table>

B. Obviously metabolic rate per gram varies dramatically among tissues. [Brain high because of cost of maintaining ionic gradients.]

C. N.B. These values change dramatically during activity, also with feeding, or with temperature. Thus, the concept of a single, mass-specific metabolic rate is artificial.

II. What are the physiological correlates of high mass-specific rates for small animals?

A. High mass-specific metabolic rates of small animals means that they must “gear up” their physiology and morphology to provide adequate nutrient and gas exchange.

B. Because cell size is independent of body size (\(\sim M^{1/3}\)), a single cell of a small animal must be metabolizing relatively intensively.

C. How can small animals meet demands of very high gas and nutrient exchange? For example, they must get lots of oxygen into the lung, into the blood, to the tissues, and to the mitochondria.

1. Small animals have relatively high respiratory rates (\(b = -.25\)).
2. Also have relatively high heart rates (\(b = -.25\)) (Perhaps 900 to 1000 beats per minute in the smallest mammals but only 30 per minute in an elephant!). Thus can rapidly transport \(O_2\), nutrients, and wastes to the cells

[3. Hemoglobin is relatively concentrated in small animals, and \(O_2\) dissociation curves shifted to the right, and greater “Bohr shift.” See future Respiration lectures.]

4. Capillary density is relatively high in small mammals. (Why is this important?)
5. Mitochondrial volume densities, mitochondrial surface areas, & enzyme activities are all greater in small animals. Why does this make sense?
6. Relative size of organs (% of total mass) varies with size. "b" for blood and muscle volume \(\sim 1\), for gut & liver \(< 1\), for skeleton \(> 1\).
7. Enzyme activities may scale negatively (citrate synthase, a key aerobic enzyme), thus enzymes can be more active in small animals.
C. Overall, small animals live life “in the fast lane.”

III. What are the physiological correlates of high metabolic rates of endotherms?

A. Endothermy and high metabolic rates in vertebrates evolved at least twice, in ancestors of mammals ("mammal-like reptiles") and in those of birds (dinosaurs). What are the physiological/morphological differences \(^2\) that account for the huge difference in metabolic rates between endotherms vs. ectotherms?

1. Not surprisingly, endotherms have large, complex lungs (high surface areas for gas exchange) and big (4-chambered) hearts
2. Size of metabolically active organs (liver, kidney, heart, brain) in mammals are almost twice the size of same organs in a lizard.
3. Mitochondrial membrane surface areas 4 to 5 times that of a lizard. (W. Fig. 8.31)
4. Enzyme activity (e.g., cytochrome oxidase, a mitochondrial enzyme important in O\(_2\) consumption) is 4 to 5 X that of a lizard. (W Fig. 8.31)

B. Conclusion: much of the huge difference in SMR between endo- & ectotherms may be accounted for by differences in (i) size of metabolically active organs (above), (ii) greater enzyme activity, as well as (ii) greater sodium/potassium transport. In effect, “there is more there there.”