Homeostasis

I. Homeostasis – Origin and Definition

A. Definition:
Homeostasis - maintenance of an internal state that is distinct from the external environment and is defended against perturbation

B. Origin:
1. 19th Century French Physiologist Claude Bernard – a critical observation on the constancy of the internal environment
   “It is the fixity of the milieu interieur which is the condition of free and independent life, all the vital mechanisms, however varied they may be, have only one object, that of preserving constant the conditions of life in the internal environment.”

   2. NOTE: Traditionally, the internal environment has been represented by the blood because it is this compartment that is readily sampled and analyzed

   3. Walter B. Cannon 1932 *The Wisdom of the Body*
   Cannon chose the term “homeostasis” to describe the process by which an animate body maintains a distinct and relatively constant internal environment

   *Cannon emphasized that the process of homeostasis is dynamic and that the body “admits some variation” in the internal environment

   4. A seminal point to remember:
   “Homeostasis is not a single optimal control condition but rather a variety or continuum that varies with the animal’s circumstances.” Donald C. Jackson, comparative physiologist

   5. “Rheostasis” (Mrovosky, 1990) or “heterostasis” (Hans Selye)

II. What are homeostatically controlled variables?

A. Examples of homeostatically controlled variables

B. Examples of variables that are NOT homeostatically controlled

C. Some homeostatically controlled variables and their normal ranges in humans

III. Control Systems – a mechanism for homeostasis

A. The negative feedback loop

   1. Components:
- **Sensor or receptor** – detects the level of the variable, produces signals sent to integrator
- **Integrator** – compares the signals from the sensor to some standard or “set point” value
- **Effector** – component capable of altering the level of the variable, under control of the integrator

2. **Examples of negative feedback loop control system**
   
a. Widely-used non-biological example: **home thermostat-controlled heating-cooling system**
   
b. Biological example – PaCO2, blood pressure, etc.
   
c. Really non-biological example: The life of a surfer

B. **What alternatives are there to negative feedback control?**

   1. **Feed-forward control** – a detected change in state leads to an anticipatory effector response
      
      Some people think respiration during exercise operates by feed-forward control – increases in ventilation are too fast for humoral (at least) feedback control

C. **Conceptual aspects of Control Systems**

   1. **Set point or set point range**
      
      A non-biological control system such as a home heating/cooling system has a real set point or set point range (set point = 69°F, e.g.).

   2. **Threshold**
      
      a. The threshold is the value of the controlled variable that creates a big enough signal (via the sensor) to cause the effector to turn on (via the integrator). For example, although the set point temperature in your house may be 69°F, the furnace may not turn on until the temperature falls to 67°F (not 68.9°F).

      b. “Hypoxic threshold”

   3. **Gain (slope)**
      
      The gain of a control system is the slope – a GRAPHICAL concept.

      “The gain of a control system describes the magnitude of the effector response as a function of the displacement of the controlled variable from its set point (the error signal).” Donald C. Jackson

IV. **The difference between homeostasis and steady-state**
A. **Steady-state**: A variable, either a homeostatically controlled variable such as body temperature or a non-homeostatically controlled variable such as VO2, may be described as steady-state if it remains fairly constant in value over the time period being considered.

B. **Homeostasis** describes the process whereby the value of a variable is defended against perturbation – this value may or may not be the within the “normal resting” range, depending on the animal’s circumstances.

C. **Examples**

D. **Another critical point to remember**:  

   “...set points or regulated values are not fixed, but may, like blood pH, change depending on ambient conditions, such as temperature, or because of changing physiological conditions or demands.” Donald C. Jackson, comparative physiologist

E. **Powers and Howley have oversimplified**:  

   “...the term homeostasis is generally reserved for describing normal resting conditions, and the term steady state is often applied to exercise where the physiological variable in question... is unchanging but may not equal the “true” resting value.”

   *Homeostasis is not abandoned during exercise!  
   *Furthermore, a value that is different from the “normal resting” value does NOT necessarily indicate homeostatic failure!  
   *Exercise stresses homeostatic mechanisms and may necessitate shifts in regulatory priorities and regulated levels.

V. **Exercise challenges homeostasis**

A. **Challenges may include**:  

   1. To **blood pressure** – BP = Q * TPR  
      Cardiac output increase during exercise  
      TPR falls  
      What happens to blood pressure?

   2. To **PaCO2** – muscle metabolism increases greatly, therefore CO2 production increases greatly. Ventilation must be increased to keep PaCO2 from increasing (PaCO2 is proportional to VCO2/VA)

   3. To **pH** – increased CO2 can cause a drop in pH (acidosis) if the CO2 is not removed by ventilation  
      lactic acid production can cause a drop in pH  
      hyperventilation can cause an increase in pH
4. To **temperature** – increased muscle metabolism causes an increase in HEAT production – that heat must be lost in order to keep body temp from increasing

5. To **water balance** – sweating and increased REWL cause a loss of body water that must be replenished

6. To **osmotic balance** – loss of water can cause an increase in plasma and/or ECW osmolarity, loss of Na+ through sweating can cause hyponatremia

**B. Exercise can bring regulatory systems into conflict – forcing a homeostatic hierarchy**

1. The compromise depends on regulatory priorities
   One sign of a person in major thermal trouble is that he or she has stopped sweating. Cessation of sweating can occur if plasma osmolarity changes cause the central controller to shift priorities from thermoregulation to water conservation. A person in this condition is on the fast track to heat stroke.

2. **Obvious but important point**: “...every part of the body is linked in some fashion to every other part” (Donald C. Jackson) and that a perturbation of one system will have consequences for other systems.

**VI. The ultimate sites of homeostasis – the brain and the intracellular compartment**

A. Brain is additionally protected by the blood brain barrier and its environment has therefore two levels of control

B. Intracellular compartment – much more difficult to study than the extracellular environment (as via blood).

C. Stress Proteins – well covered in the book