Homeostasis - I

Results of homeostasis practical in our students

Mental effort

Pulse rate | Respiratory rate | SaO2 | Skin temp | Core temp
---------|-----------------|------|-----------|-----------
-10       |                 |      |           |           
10        |                 |      |           |           
30        |                 |      |           |           
50        |                 |      |           |           
70        |                 |      |           |           
90        |                 |      |           |           
110       |                 |      |           |           
130       |                 |      |           |           
150       |                 |      |           |           

Light exercise

Heavy exercise

Osmolarity = 290 mosm/L

ion concentrations:

Na⁺ = 145 mM
K⁺ = 4 mM

Temperature (core in humans) = 37.1°C

Cells live in a fluid environment

Extracellular environment

pH = 7.4

CO₂, oxygen, glucose & other nutrients

Cells live in a fluid environment
NB: Because all biochemical processes in cells are sensitive to conditions such as temperature, pH and concentrations of reacting molecules any change in these variables may be harmful for them.

1. Unicellular organisms have no control over their environment. They are limited to living where the conditions happen to be right.

2. In complex animals and humans, cells are surrounded by the extracellular fluid which forms the "INTERNAL ENVIRONMENT" of the body. This environment must be kept stable.

3. Mammals have developed the ability to MAINTAIN THEIR INTERNAL ENVIRONMENT WITHIN NARROW LIMITS in a wide variety of external conditions. This allows these animals to survive where others cannot.

Homeostasis means maintenance of constant (static) conditions in the internal environment.

- The concept was first framed by the XIX C biologist CLAUDE BERNARD who said "the control of the internal environment is the condition of a free life".

- In 1932 WALTER CANNON introduced the term "HOMEOSTASIS" to describe this maintenance of constant conditions (in the internal environment).
In order to stay stable the system must be able to "measure" the variable, detect the errors and counteract these errors.

Terms to remember:
1. Controlled variable (temperature)
2. Sensor (receptor)
3. Integrating centre (controller)
4. Effector
5. Set point: the value to which the system is trying to return if perturbed
6. Negative feedback: the principle of operation whereby a system reacts by a change opposite to the disturbance
7. Closed loop system: the system which adjusts its operation according to the result (in this example - temperature)

Feedback
Controlled variable:

- Wrapping yourself up in a blanket
- Constriction of skin blood vessels
- Shivering
- Decrease heat loss (conserve the energy)
- Body temperature increase

Heat loss from body
Body temperature decrease

Sensors (RECEPTORS)
(Integrating centre in the brain with a "setpoint"

Effector mechanisms

Heat production increase
1. Controlled variables

<table>
<thead>
<tr>
<th>controlled variable</th>
<th>major controlling system(s)</th>
<th>behavioural components</th>
</tr>
</thead>
<tbody>
<tr>
<td>temperature</td>
<td>skin blood vessels (heat loss)</td>
<td>skeletal muscles (heat production)</td>
</tr>
<tr>
<td>oxygen &amp; CO₂</td>
<td>respiratory/cardiovascular</td>
<td></td>
</tr>
<tr>
<td>blood glucose</td>
<td>GI tract, pancreas, liver</td>
<td></td>
</tr>
<tr>
<td>osmolarity</td>
<td>kidney</td>
<td>drinking (water)</td>
</tr>
<tr>
<td>blood pH</td>
<td>respiratory system, kidney</td>
<td>???</td>
</tr>
</tbody>
</table>

2. Sensors (receptors)

Sensors (receptors) are required to "measure" controlled variables.

N.B. Nerve cells encode the information about controlled variables by frequency of action potentials. For a nerve cell measure a certain variable it should be able to generate more or less action potentials when that variable increases or decreases.

N.B. Many sensors are specialised ion channels.

Cold receptors discovered by G. Reed and colleagues

How about some chewing gum???
The cold and menthol receptor is a specialised ion channel which opens upon cooling and when menthol blinds to it.

Negative feedback is the principle of operation of homeostatic systems when system's response is directed to offset the change.

Can the system "foresee" the future? Is it possible to feed FORWARD ???

Feed-forward is when the system reacts BEFORE the actual change in controlled variable (response in anticipation).

Examples: we dress before we get cold, we get thirsty while eating salty food, before the blood concentration of NaCl has time to change.

and many more...
Positive feedbacks are also present in the body, but they are not parts of homeostatic mechanisms. They destabilise, rather than stabilise and accelerate transitions between different states.

An example of positive "feed-back": contractions of uterus during labour are stimulated by the baby’s head pressing on the cervix.

Use of antagonistic effectors

Effectors – mechanisms/organs/processes employed to bring the controlled variable to the set point.

Results of the "homeostasis" practical
Biological systems are intelligent and normally DO NOT overcompensate. SET POINT in biological systems effectively is a range of “normal” values. For example:

- blood glucose concentration range: ~ 75-110 mg/100 ml
- blood pH: 7.35-7.45

**SUMMARY:**

1. Homeostasis means “keeping the conditions for the cellular biochemistry stable”
2. Elements of a “classical” homeostatic loop: sensor, integrating centre, effector mechanisms. It is concerned with a particular “controlled variable” and operates using negative feedback to keep it near the set point.
3. Humans have numerous behavioural responses which help to maintain homeostasis.
4. Many sensors are specialised ion channels
5. Homeostatic systems include “feed forward” mechanisms (e.g. reactions which occur in advance)
6. Antagonistic effectors are used to increase the precision of control
Homeostasis - 2
(application of homeostatic principles to physiology of body systems)

EXAMPLE 1

Homeostatic principles applied to regulation of arterial blood pressure

Brainstem autonomic centres

AMPLIFIER

Afferents of the ANS

Blood pressure (mm Hg)

Activity of a baroreceptive nerve

Carotid artery

Data from Dr. H. Waki
These sensory nerve endings are thought to have stretch-sensitive Na⁺ channels.

Activation of Na⁺ channels will lead to depolarisation of the membrane of the sensory nerve ending and action potential generation.

Reflex fall in heart rate triggered by afferent baroreceptors.

An increase in blood pressure → REFLEX →

a) decrease in heart rate + b) dilation of blood vessels →

Blood Pressure Decrease

NTS = nucleus tractus solitarius

1. Find afferents and efferents of the autonomic NS
2. Label the pre- and postganglionic efferent fibres
3. Indicate transmitter they release
4. Recall the actions of the sympathetic and parasympathetic NS on the heart
Information processing by the brain

Effector part of ANS

Afferents of the ANS

Effectors

α and β

Pressure sensitive afferents

- Acetylcholine
- Noradrenaline

Symp | Para

Heart: Rate ↑ | Rate ↓
Force ↑ | Force ↓

Arterial Pressure

NORMAL

HYPERTENSIVE

Heart Rate
Interplay of autonomic nervous system and endocrine system in homeostatic control of blood pressure

**Autonomic Nervous System**
- sympathetic & parasympathetic nerves
- Frequency and force of cardiac contractions
- Tone of blood vessels, resistance to blood flow
- Volume of circulating blood
- Concentration of NaCl in plasma and extracellular fluid

**Endocrine System**
- vasopressin
- angiotensin II
- aldosterone

**BLOOD PRESSURE**

Drugs used to treat hypertension

**Autonomic Nervous System**
- Blockers of NA (S.N.S.) and ADR (E.S.)
- Blockers of NA receptors in vessels (S.N.S.) and a blocker of hormone angiotensin-II receptors (ES)

**Endocrine System**
- Diuretic drugs which block receptors of certain hormones on kidney (ES)
- Volume of circulating blood
- Concentration of NaCl in plasma and extracellular fluid

**BLOOD PRESSURE**

**EXAMPLE 2**

Homeostatic principles applied to regulation of hormone concentration

Knowledge of negative feedback loops is important for understanding of diseases and drug actions
Organisation of the endocrine circuit which operates via anterior pituitary

HYPOTHALAMUS

RELEASING FACTORS (HORMONES)

ANTERIOR PITUITARY

"Trophic" hormones

TSH, ACTH, FSH, LH

TARGET ENDOCRINE GLANDS

Thyroid, Adrenal cortex

HORMONES

thyroxine, cortisol, sex hormones

TARGET TISSUES AND ORGANS

INHIBIT

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Summary:
- The body is trying to keep the extracellular environment stable so that all chemical reactions occur at the optimal conditions. Basically, this is the idea of homeostasis.
- Homeostatic principles are applicable to essentially any physiological system of the body.
- Stability of all body functions is maintained by numerous negative feedback loops: the system responds in such a way so that to cancel any deviations from the optimal level.
- Most whole body homeostatic mechanisms involve a joint action of ANS, endocrine system and behavioural reactions.
- Failures in homeostasis lead to diseases and may be lethal.
- Medical interventions may be designed to restore homeostasis. However, drugs may cause side effects due to unwanted interactions with homeostatic negative feedback mechanisms.
Homeostatic mechanisms have limited capacity. If bleeds, MAP falls. Homeostatic mechanisms have limited capacity.

N.B. If all attempts to restore homeostasis fail, this may lead to irreversible damage and death.

Controlled variable

Medicine is about restoring homeostasis!!!

The end!