Chapter 4 Heat and Cold in Medicine

4.1 Physical Basis of Heat and Temperature

- Matter is composed of molecules in motion
- Kinetic energy (K.E.) is related with temperature (T)
- $\text{K.E.} \uparrow \Leftrightarrow T \uparrow$
- Heat
  - Energy transferred to molecules to increase T
  - Solid + heat $\Rightarrow$ liquid
  - Liquid + heat $\Rightarrow$ gas
  - Gas + heat $\Rightarrow$ ions

4.2 Thermometry and Temperature Scales

- Thermometry: indirect measurement of T
- Temperature scales
  - Fahrenheit ($^\circ$F) scale
    - Water freezes at 32$^\circ$F and boils at 212$^\circ$F
    - Normal body T (rectal) is about 98.6$^\circ$F
  - Celsius ($^\circ$C) scale
    - Water freezes at 0$^\circ$C and boils at 100$^\circ$C
    - Normal body T (rectal) is about 37$^\circ$C
  - Absolute ($^\circ$K) scale
    - Water freezes at 273.15$^\circ$K and boils at 373.15$^\circ$K
    - Normal body T (rectal) is about 310$^\circ$K
    - Absolute zero (0$^\circ$K) is –273.15$^\circ$C
- Glass thermometer
  - Increase in T of different materials $\Rightarrow$ expansion by different amounts
  - Mercury or alcohol in a glass capillary
    - Mercury or alcohol expands more than glass as $T \uparrow$
  - Mercury fever thermometer
    - T change from 0 to 100$^\circ$C in 1cm$^3$ mercury $\Rightarrow$ 1.8% change in volume
    - Capillary with smaller diameter (0.1 mm) $\Rightarrow$ high sensitivity
Magnifying glass and opaque white backing ⇒ improved visibility (Fig. 4.2)

Restriction just above the bulb ⇒ hold the maximum T

T measurement underneath the tong or in the rectum requires several minutes for stabilization (why?)

- Thermistor
  - Resistor with negative T coefficient (-5%/°C)
  - Bridge circuit in Fig. 4.3
  - Highly sensitive to detect T change of 0.01°C
  - Small mass and fast response
  - Application to pneumograph (respiration monitoring)

- Thermocouple
  - Two junctions of two different metals (copper-constantan) in Fig. 4.4
  - T difference between two junctions ⇒ voltage of 4 mV/100°C ⇒ needs amplification
  - Cold junction at 0°C using ice bath or semiconductor circuit
  - Wide T range: -190 to 300°C
  - Very small

4.3 Thermography – Mapping the Body’s Temperature

- Body surface T
  - External physical factors
  - Internal metabolic and circulatory processes near the skin (blood flow near the skin dominates)

- Thermogram: surface T map
  - Surface T above tumor is about 1°C higher ⇒ breast cancer detection ⇒ not successful
  - Radiation emitted by body
    - \[ W = \varepsilon \sigma T^4 \] : Stefan-Boltzmann law (Example 4.1)
    - \[ \lambda_{max} = \frac{2898}{T} \] : Wien’s displacement law
    - \[ T = 300°K \Rightarrow \lambda_{max} = 9.66\mu m \] (infrared region, not visible)
  - Basic thermographic unit (Fig. 4.5) and commercial instrument (Fig. 4.6)
    - Detect T difference of 0.2 or 0.1°C
    - Frame time of 2 s
- 20 min stabilization period at 21°C
- Clothing must be removed

- Breast cancer detection
  - Thermography: high false positive and false negative
  - Palpation: difficult to detect a small tumor (less than 1 cm in diameter)
  - Mammography (low energy x-ray): successful but radiation hazard
  - Biopsy: invasive, some cancer tissue may be missed

- Circulation of blood in the head
- Detection of circulatory problem in the foot of diabetics

4.4 Heat Therapy

- Heating of tissue may be beneficial to damaged tissue
  - Increase in metabolism ⇒ relaxation of the capillary system (vasodilation)
  - Increase in blood flow since blood moves to cool the heated area

- Heating methods
  - Heat conduction: hot bath, hot pack, electric heating pad, hot paraffin, etc.
    - Contact area
    - T difference
    - Duration
    - Thermal conductivity
  - Radiant (IR) heat: glowing wire coil, incandescent lamp, sun, etc.
    - IR wavelength: 800 to 40,000 nm
    - Waves penetrate the skin by 3 mm and increase the surface T
    - Excessive exposure ⇒ reddening (erythema), swelling (edema), browning and hardening of the skin
  - Electrical heating: electric currents through resistive tissues produce joule heating
    - Short-wave diathermy: radio frequency (500 kHz), muscle spasm, pain, degenerative joint disease, bursitis, use of electrodes (Fig. 4.9) and use of magnetic induction (Fig.4.10)
    - Microwave diathermy: radar frequency (900 MHz), fractures, sprains and strains, bursitis, injuries to tendons, arthritis
    - Internal heating is possible ⇒ treatment of inflammation of the skeleton, bursitis, neuralgia
  - Ultrasonic diathermy: ultrasonic waves vibrate tissues producing heat
Treatment of cancer by heat is promising (tumor heated to about 42°C for 20 to 30 min)

**4.5 Use of Cold in Medicine**

- Cryogenics: science and technology of producing and using very low temperature
- Cryobiology: study of low-temperature effects in biology and medicine
- Cryogenic fluids
  - Liquid helium: -269°C
  - Liquid nitrogen: -196°C
- Container: Dewar vessels (Fig. 4.11)
  - Glass or thin stainless steel: minimize conductive heat loss
  - Vacuum space: minimize convective heat loss
  - Silvered or polished surface: reflect radiation
- Transfer of cryogenic fluids: two polished concentric metal pipes with vacuum between walls
- Cryogenic methods in medicine
  - Long-term preservation of blood, sperm, bone marrow, and tissues
  - Cryonics: preservation and revival of living tissues at low T
  - Survival behavior as a function of cooling rate (Fig. 4.12): different tissues show different behavior
- Storage of blood
  - Thin-walled container (Fig.4.13)
  - Blood-sand method

**4.6 Cryosurgery**

- Cryosurgery: cryogenic methods to destroy cells
  - Less amount of bleeding
  - Volume of tissue destroyed can be controlled by T
  - Little pain sensation since low T desensitize nerves
- Cryoknife or Cooper cryosurgery system (Fig. 4.14)
  - Treatment of Parkinson’s disease
  - Destroy a part of the thalamus in the brain
- Treatment of tumors and warts
- Eye surgery
• Repair of a detached retina
• Cataract surgery (removal of a darkened lens)

4.7 Safety with Cryogenics

• Containers must be securely fixed
• Pressure-reducing regulator must be used
• Cryogenic fluid causes “freeze burns”
• Adequate ventilation is required
• Open flame and smoking are prohibited
• Special care for oxygen since it is highly flammable

● Homework
  ○ Review questions: #3, #10