6. Indirect Flow

- Venous occlusion method
- Plethysmography
- Clearance method
- Heat transport method
- Laser Doppler method
- Laser Doppler imaging method and others bioimaging methods (MRI, PET)

Venous Occlusion Method

- Proximal pressure
- Distal pressure
- Above Systolic ABP
- Above Venous BP
- Below Diastolic ABP
- Blood flow $Q$ is determined by the rate of increase of the volume, $dV/dt$.

Water-filled Plethysmography

- Iris diaphragm
- Volume change $\rightarrow$ water level
- Cuff
- Soft rubber diaphragm

Air-filled Plethysmography

- Small bore tubes
- Air resistance
- Differential pressure transducer
- Pressure difference across a small air resistance is detected to estimate the air flow rate.

Volume change can be obtained by integrating the air flow rate.
Mercury-strain-gauge Plethysmography

circumference change → electrical resistance change

Capacitance Plethysmography

ε: dielectric constant of medium between the electrodes
L: length of the electrode.
D: cylinder diameter
s: spacing

\[ C = \frac{\varepsilon L \pi D}{s} \]

Impedance Plethysmography

0.1-10mA 20-200kHz

Outer = current electrodes
Inner = voltage electrodes

Parallel Conductor Model for Impedance Plethysmography

\[ Z_0 = \frac{\rho_0 L}{A_0} \]
\[ Z_b = \frac{\rho_b L}{A_b} \]

If \( \Delta Z = Z - Z_0 \ll Z_0 \)

then \( Z_b \approx \frac{Z_0^2}{\Delta Z} \)

\[ V_b = \frac{\rho_b L^2}{Z_b} = -\frac{\rho_b L^2}{Z_0^2} \Delta Z \]

It implies that the blood volume added to the segment can be estimated by the impedance change due to the increase of the blood volume, as long as the blood resistivity is known.
Impedance Cardiography

Kubicek equation

\[ SV = \frac{\rho s L^2}{Z_0^2} \Delta Z \]

where \( \Delta Z = T \left( \frac{dZ}{dt} \right)_{\text{max}} \)

\( T \) = the left ventricular ejection time (s)

Real Measurement

Tape Electrodes for Plethysmography
**Spot and Band Electrodes**

(a) new spot- and Kubicek's band-electrode array

(b) spot-electrode

(c) band-electrode

**Clearance Method**

\[ V_0 \frac{dc(t)}{dt} = q \cdot c(t) \]

\[ V_0 \frac{dc(t)}{dt} = q \cdot c(t) \]

\[ c(t) = V_0 e^{-\frac{t}{\tau}} \]

Find 36.8% \( V_0 \) to determine \( \tau \) from curve \( c(t) \)

**Simplified Model**

change in indicator concentration in this region

\[ \frac{dc}{dt} = q(c_a - c_v) \]

perfusion blood flow rate per unit weight of the tissue

\[ \frac{q}{\tau} \]

\[ c = c_0 e^{-\frac{qt}{\lambda}} = c_0 e^{-\frac{t}{\tau}} \]

\[ c = \lambda c_v \]

\[ c_c \]

**Kety-Schmidt Method**

flow rate is determined by the process of increasing the indicator concentration in the tissue, when the indicator is introduced continuously into the arterial blood.

cerebral blood flow measurement by Kety-Schmidt in 1948 using nitrous oxide (N₂O).
Clearance Curve in Muscle

A small amount of saline containing radioactive indicator such as $^{133}\text{Xe}$ is injected into the muscle, then the clearance curve is recorded externally by a scintillation counter.

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Scintillation Counter

A scintillation counter consists of a transparent crystal that fluoresces when struck by ionizing radiation. A sensitive photomultiplier tube (PMT) measures the light from the crystal. The PMT is attached to an electronic amplifier to quantify the amplitude of the signals produced by the PMT.

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Skin Blood Flow by RI Clearance

$^{133}\text{Xe}$ gas is added to a small chamber adhering to the surface of the skin for about 3 min, and then the chamber is removed.

Because the retrograde diffusion of $^{133}\text{Xe}$ from the skin to the environment is negligible compared to the transport by the blood flow, the skin blood flow is determined from the clearance curve.

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Hydrogen Clearance Method

- Hydrogen gas ($\text{H}_2$) can be an indicator for tissue blood flow measurement by the clearance method, because it diffuses freely into the tissue.
- The dissolved hydrogen gas in the blood is rapidly removed from lung, and its concentration can be detected by a fine platinum electrode.
- To introduce hydrogen gas into the tissue, different methods such as the inhalation method, injection of hydrogen dissolved saline into the artery, or generation of hydrogen gas by electrolysis can be used.
- The clearance curve is recorded as the change of hydrogen partial pressure in the tissue.
Hydrogen Clearance Method

• When a **platinum electrode** and a **reference electrode** are placed on or inserted into the tissue, and a positive potential is given to the platinum electrode relative to the reference electrode, the **oxidation reaction** occurs on the platinum electrode surface.

\[ \text{H}_2 \rightarrow 2\text{H}^+ + 2\text{e}^- \]

• While \( \text{H}_2 \) is consumed at the electrode surface by above reaction, \( \text{H}_2 \) is supplied from the surrounding media by diffusion, and thus the reaction will continue. Consequently a constant current will be obtained at an equilibrium, which is proportional to the \( \text{H}_2 \) flux, corresponding to the partial pressure of hydrogen gas in the surrounding media.

Contact Electrode

Gastric mucosal blood flow measurement

Heat Transport Method

• When a region of the tissue is heated or cooled, continuously or step-wise, heat transport occurs between the tissue and the perfusing blood, and the tissue blood flow can be estimated from the amount of heat transfer.

• The rate of heat transfer \( H \) from the tissue of temperature \( T_t \) and the arterial blood of temperature \( T_a \) is expressed as

\[ H = \rho c q (T_t - T_a) \]

where \( \rho \) and \( c \) are the density and specific heat of the blood, respectively, \( q \) is tissue blood flow rate.

• \( q \) can be determined from \( H \) when a constant temperature difference \( (T_t - T_a) \) is maintained between a region of the tissue and the arterial blood.

• \( H \) equals to the heat applied to the tissue in unit time, which is the power consumption of the heater in the probe.
Tissue Blood Flowmeter

- Needle type probe is inserted into a small region of the tissue.

Skin Blood Flowmeter

- Contact type

Diagram showing different components and parts of the probes.
**Laser Doppler Method**

- Tissue is a highly scattering and absorbing medium which has a higher refractive index than air.
- A laser beam that is brought to impinge on the skin surface will be partly reflected back (4%-5% of the incident energy) owing to specular surface reflections.
- The remaining energy penetrates the tissue as scattering and absorption.
- Scattering occurs when difference in refractive indices between different medium. The directions of scattering vary on the size and shape of the scattering particles.
- A continuous and noninvasive method to measure the tissue blood flow by laser Doppler shift.
- Widely used in dermatology, plastic surgery, and gastrointestinal surgery.

**Light Scattering Measurement**

\[ \Delta f = \frac{c \Delta f}{f_0} \]

- Source velocity can be determined by \( V = \frac{c \Delta f}{f_0} \)
- Total Doppler shift \( \Delta f = (K_s - K_o) \cdot \frac{V}{2\pi} = K \cdot \frac{V}{2\pi} \)
- \( |K| = |K_s - K_o| = \frac{4\pi}{\lambda} \sin \frac{\theta}{2} \)

**Arrangement of Optical Fibers**

**Laser Doppler Flowmeter**

PeriMed PERIFLUX
Laser Doppler Scanner

Laser Doppler Imaging System

Blood Flow Image