Biomedical Instrumentation

Prof. Dr. Nizamettin AYDIN

naydin@yildiz.edu.tr
naydin@ieee.org
http://www.yildiz.edu.tr/~naydin

1

Measurement of Flow and Volume of Blood

$$F = \frac{dV}{dt} = \frac{dm/dt}{\Delta C}$$

$$F = \frac{dm/dt}{C_a - C_v}$$

$$= \frac{0.25 \text{ liter/min}}{(0.20 \text{ liter/liter}) - (0.15 \text{ liter/liter})}$$

$$= 5 \text{ liters/min}$$

Figure 8.1   Several methods of measuring cardiac output. In the Fick method, the indicator is O2; consumption is measured by a spirometer. The arterial-venous concentration difference is measured by drawing samples through catheters placed in an artery and in the pulmonary artery. In the dye-dilution method, dye is injected into the pulmonary artery and samples are taken from an artery. In the thermodilution method, cold saline is injected into the right atrium and temperature is measured in the pulmonary artery.

$$m = \int_0^{t_1} F_i C(t)\,dt$$

$$F = \frac{m}{\int_0^{t_1} C(t)\,dt}$$

$$F = \frac{m}{\int_0^{t_1} [\Delta C(t)]\,dt}$$

$$F = \frac{Q}{\rho_b C_b \int_0^{t_1} \Delta T_b(t)\,dt} \ (\text{m}^3/\text{s})$$

Figure 8.2   Rapid-injection indicator-dilution curve. After the bolus is injected at time A, there is a transportation delay before the concentration begins rising at time B. After the peak is passed, the curve enters an exponential decay region between C and D, which would continue decaying along the dotted curve to t1 if there were no recirculation. However, recirculation causes a second peak at E before the indicator becomes thoroughly mixed in the blood at F. The dashed curve indicates the rapid recirculation that occurs when there is a hole between the left and right sides of the heart.

Figure 8.3 Electromagnetic flowmeter. When blood flows in the vessel with velocity u and passes through the magnetic field B, the induced emf e is measured at the electrodes shown. When an ac magnetic field is used, any flux lines cutting the shaded loop induce an undesired transformer voltage.

$$e = \int_0^{L_1} \mathbf{u} \times \mathbf{B} \cdot d\mathbf{L}$$

$$e = BLu$$

Figure 8.4   Solid lines show the weighting function that represents relative velocity contributions (indicated by numbers) to the total induced voltage for electrodes at the top and bottom of the circular cross section. If the vessel wall extends from the outside circle to the dashed line, the range of the weighting function is reduced. (Adapted from J. A. Shercliff, *The Theory of Electromagnetic Flow Measurement,* ©1962, Cambridge University Press.)

Figure 8.5   Electromagnetic flowmeter waveforms The transformer voltage is 90° out of phase with the magnet current. Other waveforms are shown solid for forward flow and dashed for reverse flow. The gated signal from the gated-sine-wave flowmeter includes less area than the inphase signal from the quadrature-suppression flowmeter.

Figure 8.6   The quadrature-suppression flowmeter detects the amplifier quadrature voltage. The quadrature generator feeds back a voltage to balance out the probe-generated transformer voltage.

For gated sine wave, waveforms are exactly like those in Fig. 8.5. Sample the composite signal when the transformer voltage is zero." Transformer voltage is proportional to *dB/dt*. Taking the derivative of square wave *B* yields spikes at transitions. Because the amplifier is not perfect, these take time to decay. Best time to sample is near the end of transformer voltage = 0. Trapezoidal *B* yields reasonable *dB/dt* so sample during time transformer voltage = 0.

Figure 8.7   The toroidal-type cuff probe has two oppositely wound windings on each half of the core. The magnetic flux thus leaves the top of both sides, flows down in the center of the cuff, enters the base of the toroid, and flows up through both sides.

$$d_{nf} = \frac{D^2}{4\lambda} \qquad \sin \phi = \frac{1.2\lambda}{D}$$

Figure 8.8   Near and far fields for various transducer diameters and frequencies. Beams are drawn to scale, passing through a 10 mm-diameter vessel. Transducer diameters are 5, 2, and 1 mm. Solid lines are for 1.5 MHz, dashed lines for 7.5 MHz.

$$t = \frac{distance}{conduction\ velocity} = \frac{D}{c \pm \hat{u}\cos\theta} \qquad \Delta t = \frac{2D\hat{u}\cos\theta}{(c^2 - \hat{u}^2\cos^2\theta)} \cong \frac{2D\hat{u}\cos\theta}{c^2}$$

Figure 8.9   Ultrasonic transducer configurations (a) A transit-time probe re-quires two transducers facing each other along a path of length *D* inclined from the vessel axis at an angle *θ*. The hatched region represents a single acoustic pulse traveling between the two transducers, (b) In a transcutaneous probe, both transducers are placed on the same side of the vessel, so the probe can be placed on the skin. Beam intersection is shown hatched, (c) Any transducer may contain a plastic lens that focuses and narrows the beam, (d) For pulsed operation, the transducer is loaded by backing it with a mixture of tungsten powder in epoxy. This increases losses and lowers *Q*. Shaded region is shown for a single time of range gating, (e) A shaped piece of Lucite on the front loads the transducer and also refracts the beam, (f) A transducer placed on the end of a catheter beams ultrasound down the vessel, (g) For pulsed operation, the transducer is placed at an angle.

$$\frac{f_d}{f_0} = \frac{u}{c}$$

$$f_d = \frac{2 f_0 u \cos \theta}{c}$$

$$\frac{f_d}{f_0} = \frac{2u}{c+u} \cong \frac{2u}{c}$$

$$f_d = \frac{2(7 \times 10^6 \text{ Hz})(1.5 \text{ m/s}) \cos 45°}{1500 \text{ m/s}} \cong 10 \text{ kHz}$$

Figure 8.10 Doppler ultrasonic blood flowmeter. In the simplest instrument, ultrasound is beamed through the vessel walls, back-scattered by the red blood cells, and received by a piezoelectric crystal.

Figure 8.11 Directional Doppler block diagram (a) Quadrature-phase detector. Sine and cosine signals at the carrier frequency are summed with the RF output before detection. The output C from the cosine channel then leads (or lags) the output S from the sine channel if the flow is away from (or toward) the transducer, (b) Logic circuits route one-shot pulses through the top (or bottom) AND gate when the flow is away from (or toward) the transducer. The differential amplifier provides bidirectional output pulses that are then filtered.

$$f_r > 2f_d$$

$$f_r < \frac{c}{2R_m}$$

$$u_m(\cos \theta)R_{max} < \frac{c^2}{8f_0}$$

Figure 8.12 Directional Doppler signal waveforms (a) Vector diagram. The sine wave at the carrier frequency lags the cosine wave by 90°. If flow is away from the transducer, the Doppler frequency is lower than the carrier. The short vector represents the Doppler signal and rotates clockwise, as shown by the numbers 1, 2, 3, and 4. (b) Timing diagram. The top two waves represent the single-peak envelope of the carrier plus the Doppler before detection. Comparator outputs respond to the cosine channel audio signal after detection. One-shot pulses are derived from the sine channel and are gated through the correct AND gate by comparator outputs. The dashed lines indicate flow toward the transducer.

$$\frac{W}{\Delta T} = a + b \log u$$

Figure 8.13 Thermal velocity probes (a) Velocity-sensitive thermistor *Ru* is exposed to the velocity stream. Temperature-compensating thermistor *R,* is placed within the probe, (b) Thermistors placed down- and upstream from *Ru* are heated or not heated by *Ru,* thus indicating velocity direction, (c) Thermistors exposed to and shielded from flow can also indicate velocity direction.

Figure 8.14 Thermal velocity meter circuit. A velocity increase cools *Ru,* the velocity-measuring thermistor. This increases voltage to the noninverting op-amp input, which increases bridge voltage *vb* and heats *Ru*. *Rt* provides temperature compensation.

Figure 8.15 In chamber plethysmography, the venous-occlusion cuff is inflated to 50 mm Hg (6.7 kPa), stopping venous return. Arterial flow causes an increase in volume of the leg segment, which the chamber measures. The text explains the purpose of the arterial-occlusion cuff.

Figure 8.16 After venous-occlusion cuff pressure is turned on, the initial volume-versus-time slope is caused by arterial inflow. After the cuff is released, segment volume rapidly returns to normal (A). If a venous thrombosis blocks the vein, return to normal is slower (B).

$$Z_b = \frac{\rho_b L}{\Delta A}$$

$$\Delta V = L\,\Delta A = \frac{\rho_b L^2}{Z_b}$$

$$\Delta Z = \frac{Z Z_b}{Z + Z_b} - Z = \frac{-Z^2}{Z + Z_b}$$

$$\frac{1}{Z_b} \cong \frac{-\Delta Z}{Z^2}$$

$$\Delta V = \frac{-\rho_b L^2 \Delta Z}{Z^2}$$

Figure 8.17 (a) A model for impedance plethysmography. A cylindrical limb has length L and cross-sectional area A. With each pressure pulse, A increases by the shaded area ΔA (b) This causes impedance of the blood, Z_b, to be added in parallel to Z. (c) Usually ΔZ is measured instead of Z_b

Figure 8.18 In two-electrode impedance plethysmography, switches are in the position shown, resulting in a high current density (solid lines) under voltage-sensing electrodes. In four-electrode impedance plethysmography, switches are thrown to the other position, resulting in a more uniform current density (dashed lines) under voltage-sensing electrodes.

Figure 8.19 In four-electrode impedance plethysmography, current is injected through two outer electrodes, and voltage is sensed between two inner electrodes. Amplification and demodulation yield $Z + \Delta Z$. Normally, a balancing voltage v_b is applied to produce the desired ΔZ. In the automatic-reset system, when saturation of v_o occurs, the comparator commands the sample and hold to sample $Z + \Delta Z$ and hold it as v_b. This resets the input to the final amplifier and v_o zero. Further changes in ΔZ cause changes in v_o without saturation.

Figure 8.20 (a) Light transmitted into the finger pad is reflected off bone and detected by a photosensor, (b) Light transmitted through the aural pinna is detected by a photosensor.

Figure 8.21 In this photoplethysmograph, the output of a light-emitting diode is altered by tissue absorption to modulate the phototransistor. The dc level is blocked by the capacitor, and switch S restores the trace. A noninverting amplifier can drive low impedance loads, and it provides a gain of 100.