Biomedical Instrumentation

Prof. Dr. Nizamettin AYDIN

naydin@yildiz.edu.tr

naydin@ieee.org

http://www.yildiz.edu.tr/~naydin

1

Blood Pressure and Sound

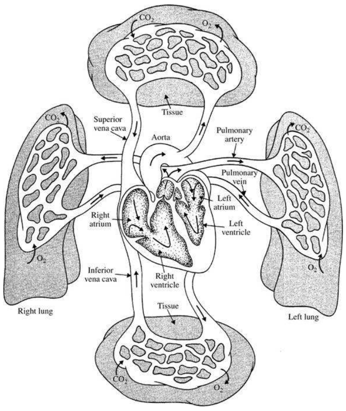


Figure 7.1 The left ventricle ejects blood into the systemic circulatory system. The right ventricle ejects blood into the pulmonary circulatory system.

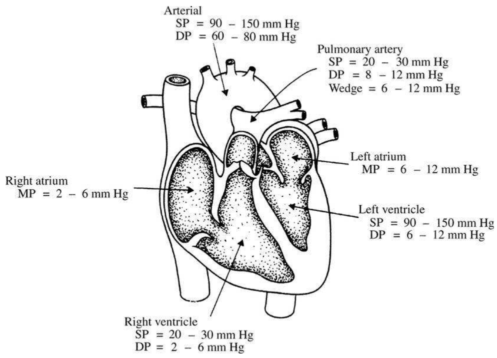


Figure 7.2 Typical values of circulatory pressures SP is the systolic pressure, DP the diastolic pressure, and MP the mean pressure.

Figure 7.3 Extravascular pressure-sensor system A catheter couples a flush solution (heparinized saline) through a disposable pressure sensor with an integral flush device to the sensing port. The three-way stopcock is used to take blood samples and zero the pressure sensor.

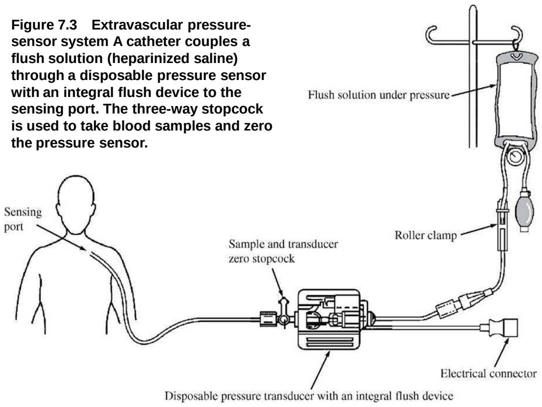
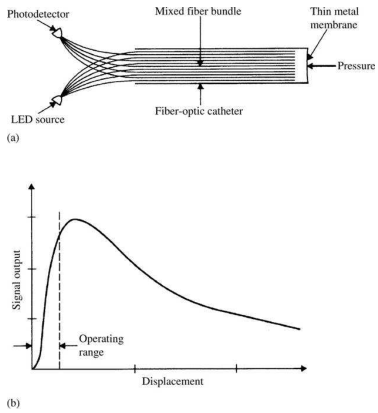


Figure 7.4 (a) Schematic diagram of an intravascular fiber-optic pressure sensor. Pressure causes deflection in a thin metal membrane that modulates the coupling between the source and detector fibers, (b) Characteristic curve for the fiber-optic pressure sensor.



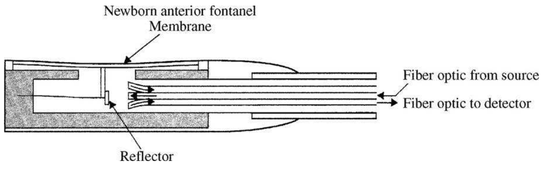
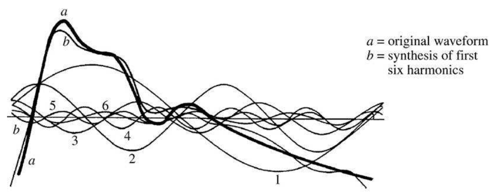


Figure 7.5 Fiber-optic pressure sensor for intracranial pressure measure-ments in the newborn. The sensor membrane is placed in contact with the anterior fontanel of the newborn.



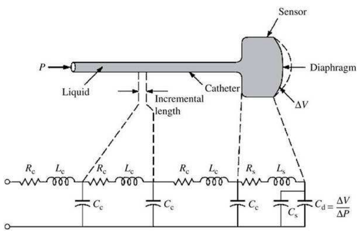
Harmonic	Amplitude (%)
1	100
2	63.2
3	29.6
4	22.2
5	14.8
6	11.8

Figure 7.6 The first six harmonics of the blood-pressure waveform. The table gives relative values for amplitudes. (From T. A. Hansen, "Pressure Measure-ment in the Human Organism," *Acta Physiologica Scandinavica*, 1949, 19, Suppl. 68, 1–227. Used with permission.)

$$R_c = \frac{\Delta P}{F}\left(\mathrm{Pa \cdot s/m^3}\right)$$

$$R_c = \frac{\Delta P}{\bar{u}A}$$

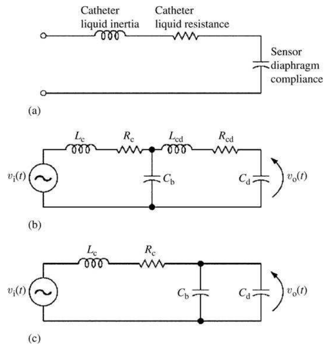
$$R_c = \frac{8\eta L}{\pi r^4}$$



$$L_c = \frac{\Delta P}{dF/dt}\left(\mathrm{Pa \cdot s^2/m^3}\right) \quad L_c = \frac{\Delta P}{aA} \quad L_c = \frac{m}{A^2} \quad L_c = \frac{\rho L}{\pi r^2}$$

Figure 7.7 (a) Physical model of a catheter-sensor system, (b) Analogous electric system for this catheter-sensor system. Each segment of the catheter has its own resistance *R*c, inertance *L*c, and compliance *C*c. In addition, the sensor has resistance *R*s, inertance, *L*s, and compliance *C*s. The compliance of the diaphragm is *C*d.

Figure 7.8 (a) Simplified analogous circuit. Compliance of the sensor diaphragm is larger than compliance of catheter or sensor cavity for a bubble-free, noncompliant catheter. The resistance and inertance of the catheter are larger than those of the sensor, because the catheter has longer length and smaller diameter, (b) Analogous circuit for catheter–sensor system with a bubble in the catheter. Catheter properties proximal to the bubble are inertance *L*c and resistance *R*c. Catheter properties distal to the bubble are *L*cd and *R*tf. Compliance of the diaphragm is *C*d; compliance of the bubble is *C*b. (c) Simplified analogous circuit for catheter–sensor system with a bubble in the catheter, assuming that *L*cd and *R*cd are negligible with respect to *R*c and *L*c.



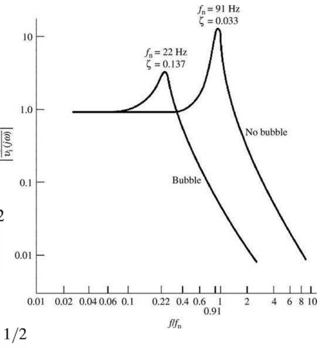
$$C_d = \frac{\Delta V}{\Delta P} = \frac{1}{E_d} \qquad C_t = \frac{\Delta V}{\Delta P_d} + \frac{\Delta V}{\Delta P_b}$$

Table 7.1 Mechanical Characteristics of Fluids

Parameter	Substance	Temperature	Value
η	Water	20 °C	0.001 Pa·s
η	Water	37 °C	0.0007 Pa·s
η	Air	20 °C	0.000018 Pa·s
ρ	Air	20 °C	1.21 kg/m^3
$\Delta V/\Delta P$	Water	20 °C	0.53×10^{-15} m^5/N per ml volume
η	Blood	All	$\cong 4 \times \eta$ for water

Table 7.1

Figure 7.9 Frequency-response curves for catheter–sensor system with and without bubbles. Natural frequency decreases from 91 Hz to 22 Hz and damp-ing ratio increases from 0.033 to 0.137 with the bubble present.



$$f_n = \frac{r}{2}\left(\frac{1}{\pi\rho L}\frac{\Delta P}{\Delta V}\right)^{1/2}$$

$$\zeta = \frac{4\eta}{r^3}\left(\frac{L(\Delta V/\Delta P)}{\pi\rho}\right)^{1/2}$$

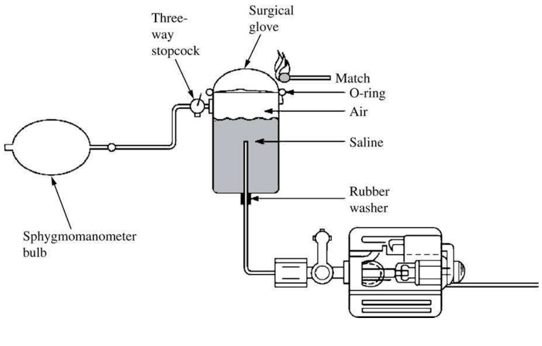


Figure 7.10 Transient-response technique for testing a pressure-sensor-catheter-sensor system.

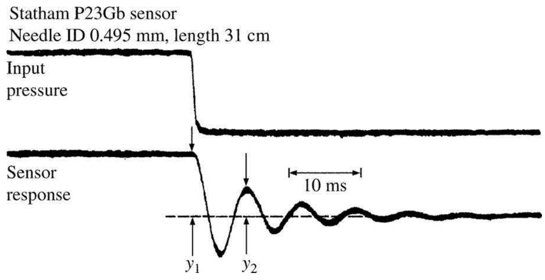


Figure 7.11 Pressure-sensor transient response Negative-step input pressure is recorded on the top channel; the bottom channel is sensor response for a Statham P23Gb sensor connected to a 31 cm needle (0.495 mm ID). (From I. T. Gabe, "Pressure Measurement in Experimental Physiology," in D. H. Bergel, ed., Cardiovascular Fluid Dynamics, vol. I, New York: Academic Press, 1972.)

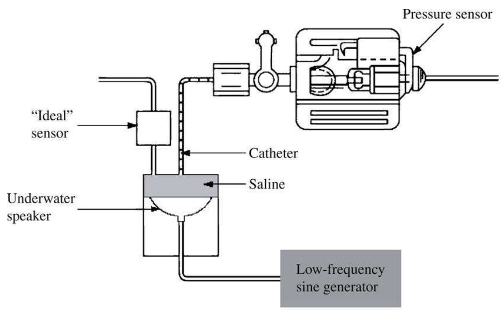


Figure 7.12 A sinusoidal pressure-generator test system A low-frequency sine generator drives an underwater-speaker system that is coupled to the catheter of the pressure sensor under test. An "ideal" pressure sensor, with a frequency response from 0 to 100 Hz, is connected directly to the test chamber housing and monitors input pressure.

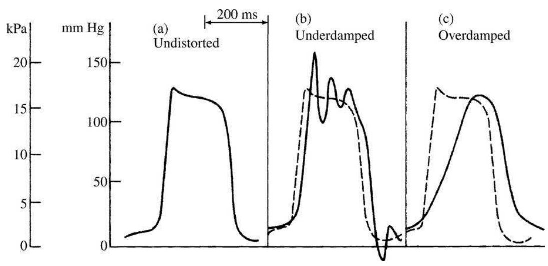


Figure 7.13 Pressure-waveform distortion (a) Recording of an undistorted left-ventricular pressure waveform via a pressure sensor with bandwidth dc to 100 Hz. (b) Underdamped response, where peak value is increased. A time delay is also evident in this recording, (c) Overdamped response that shows a significant time delay and an attenuated amplitude response.

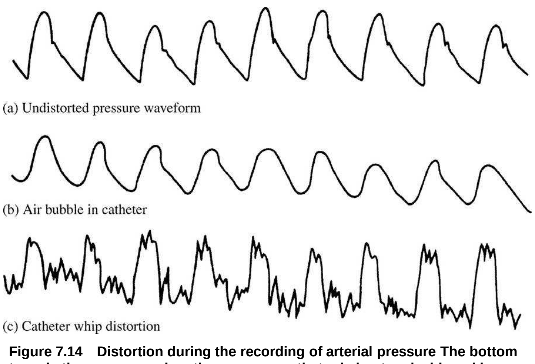


Figure 7.14 Distortion during the recording of arterial pressure The bottom trace is the response when the pressure catheter is bent and whipped by accelerating blood in regions of high pulsatile flow.

Figure 7.15 Correlation of the four heart sounds with electric and mechanical events of the cardiac cycle.

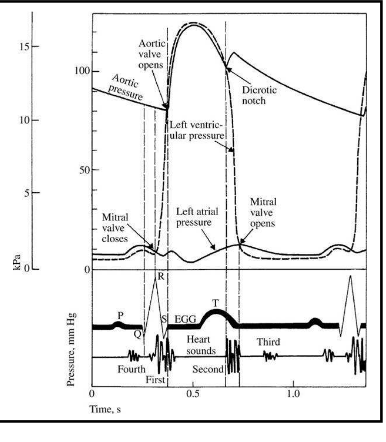
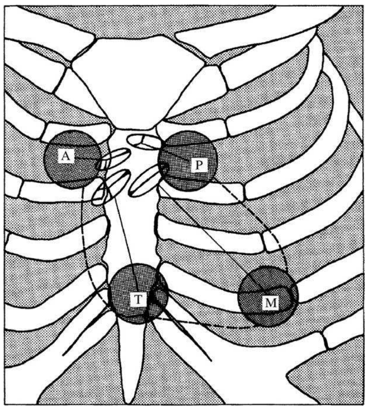


Figure 7.16 Auscultatory areas on the chest A, aortic; P, pulmonary; T, tricuspid; and M, mitral areas. (From A. C. Burton, Physiology and Biophysics of the Circulation, 2nd ed. Copyright © 1972 by Year Book Medical Publishers, Inc., Chicago. Used by permission.)



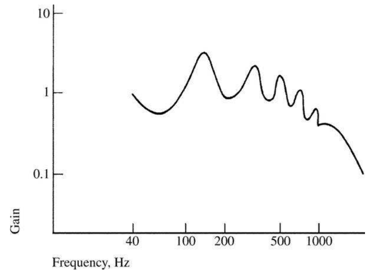


Figure 7.17 The typical frequency-response curve for a stethoscope can be found by applying a known audiofrequency signal to the bell of a stethoscope by means of a headphone-coupler arrangement. The audio output of the stethoscope earpiece was monitored by means of a coupler microphone system. (From P. Y. Ertel, M. Lawrence, R. K. Brown, and A. M. Stern, Stethoscope Acoustics I, "The Doctor and his Stethoscope." Circulation 34, 1966; by permission of American Heart Association.)

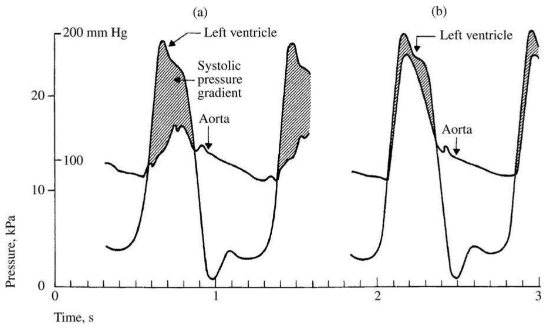
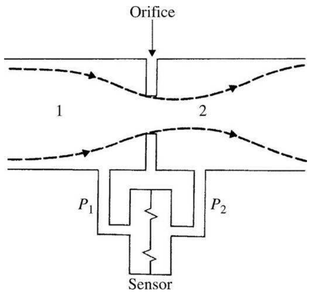


Figure 7.18 (a) Systolic pressure gradient (left ventricular-aortic pressure) across a stenotic aortic valve, (b) Marked decrease in systolic pressure gradient with insertion of an aortic ball valve.

Figure 7.19 Model for deriving equation for heart-valve orifice area *P1* and *P2* are upstream and downstream static pressures. Velocity *u* is calculated for minimal flow area *A* at location 2.



$$P_t = P + \rho g h + \frac{\rho u^2}{2}$$

$$P_1 - P_2 = \frac{\rho u^2}{2}$$

$$A = \frac{F}{u} = F\left(\frac{\rho}{2(P_1 - P_2)}\right)^{1/2}$$

$$A = \frac{F}{c_d}\left(\frac{\rho}{2(P_1 - P_2)}\right)^{1/2}$$

Table 7.2 Relative Importance of the Kinetic-Energy Term in Different Parts of the Circulation

Vessel	Vel (cm/s)	KE (mm Hg)	Systolic (mm Hg)	Systolic (kPa)	% KE of Total
Aorta (systolic)					
At rest	100	4	120	(16)	3
Cardiac output at 3 × rest	300	36	180	(24)	17
Brachial artery					
At rest	30	0.35	110	(14.7)	0.3
Cardiac output at 3 × rest	90	4	120	(16)	3
Venae cavae					
At rest	30	0.35	2	(0.3)	12
Cardiac output at 3 × rest	90	3.2	3	(0.4)	52
Pulmonary artery					
At rest	90	3	20	(2.7)	13
Cardiac output at 3 × rest	270	27	25	(3.3)	52

SOURCE: From A. C. Burton, *Physiology and Biophysics of the Circulation*. Copyright 1972 by Year Book Medical Publishers, Inc., Chicago. Used by permission.

Table 7.2

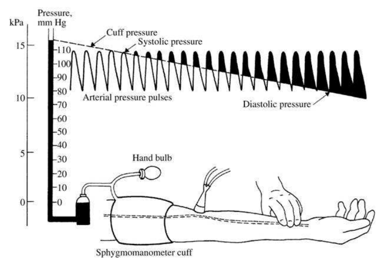


Figure 7.20 Typical indirect blood-pressure measurement system The sphygmomanometer cuff is inflated by a hand bulb to pressure above the systolic level. Pressure is then slowly released, and blood flow under the cuff is monitored by a microphone or stethoscope placed over a downstream artery. The first Korotkoff sound detected indicated systolic pressure, whereas the transition from muffling to silence brackets diastolic pressure. (From R.F. Rushmer, *Cardiovascular Dynamics*, 3rd ed., 1970. Philadelphia: W.B. Saunders Co. Used with permission.)

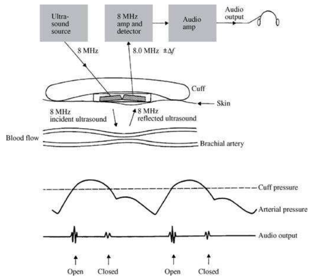


Figure 7.21 Ultrasonic determination of blood pressure A compression cuff is placed over the transmitting (8 MHz) and receiving (8 MHz ± Δ*f*) crystals. The opening and closing of the blood vessel are detected as the applied cuff pressure is varied. (From H. F. Stegall, M. B. Kardon, and W. T. Kemmerer, "Indirect Measurement of Arterial Blood Pressure by Doppler Ultrasonic Sphygmomanometry," *J. Appl. Physiol*., 1968, 25, 793-798. Used with permission.)

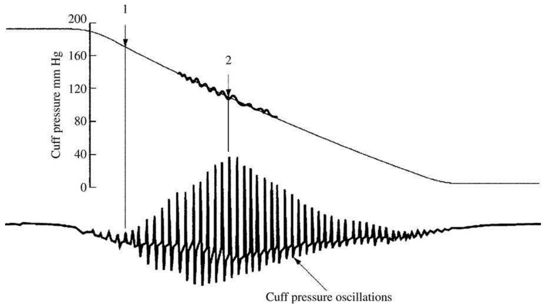


Figure 7.22 The oscillometric method A compression cuff is inflated above systolic pressure and slowly deflated. Systolic pressure is detected (Point 1) where there is a transition from small amplitude oscillations (above systolic pressure) to increasing cuff-pressure amplitude. The cuff-pressure oscillations increase to a maximum (Point 2) at the mean arterial pressure.

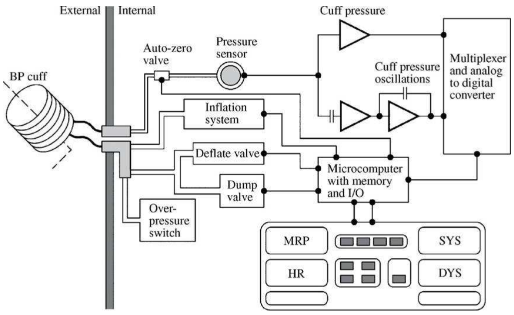


Figure 7.23 Block diagram of the major components and subsystems of an oscillometric blood-pressure monitoring device, based on the Dinamap unit, I/O = input/output; MAP = mean arterial pressure; HR = heart rate; SYS = systolic pressure; DYS = diastolic pressure. From Ramsey M III. Blood pressure monitoring: automated oscillometric devices, *J. Clin. Monit*. 1991, 7, 56–67.

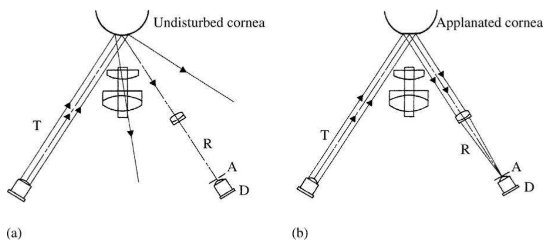


Figure 7.24 Monitoring system for noncontact applanation tonometer (From M. Forbes, G. Pico, Jr., and B. Grolman, "A Noncontact Applanation Tonometer, Description and Clinical Evaluation," *J. Arch. Ophthalmology*, 1975, 91, 134–140. Copyright © 1975, American Medical Association. Used with permission.)

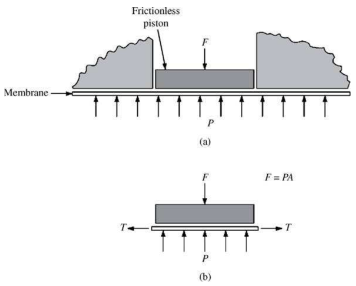


Figure 7.25 Idealized model for an arterial tonometer, (a) a flattened portion of an arterial wall (membrane). *P* is the blood pressure in a superficial artery, and *F* is the force measured by a tonometer transducer, (b) a free-body diagram for the idealized model of (a) in which *T* is the membrane tensile force perpendicular to both *F* and *P*. From Eckerle, J. D., "Tonometry, arterial," in J. G. Webster (ed.), *Encyclopedia of Medical Devices and Instrumentation*. 2nd ed. New York: Wiley, 2006, vol. 6, pp. 402–410.

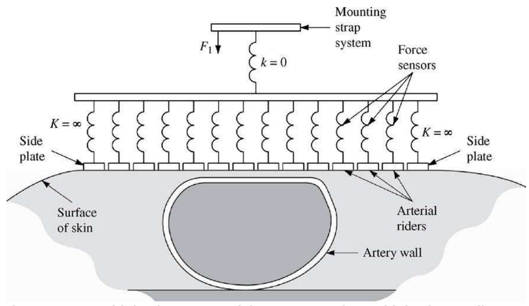


Figure 7.26 Multiple-element arterial tonometer. The multiple element linear array of force sensors and arterial riders are used to position the system such that some element of the array is centered over the artery. From Eckerle, J. D., "Tonometry, arterial," in J. G. Webster (ed.), *Encyclopedia of Medical Devices and Instrumentation*. 2nd ed. New York: Wiley, 2006, vol. 6, pp. 402–410.