

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Departments of Electrical Engineering, Mechanical Engineering, and the Harvard-MIT Division
of Health Sciences and Technology

6.022J/2.792J/BEH.371J/HST542J: Quantitative Physiology: Organ Transport Systems

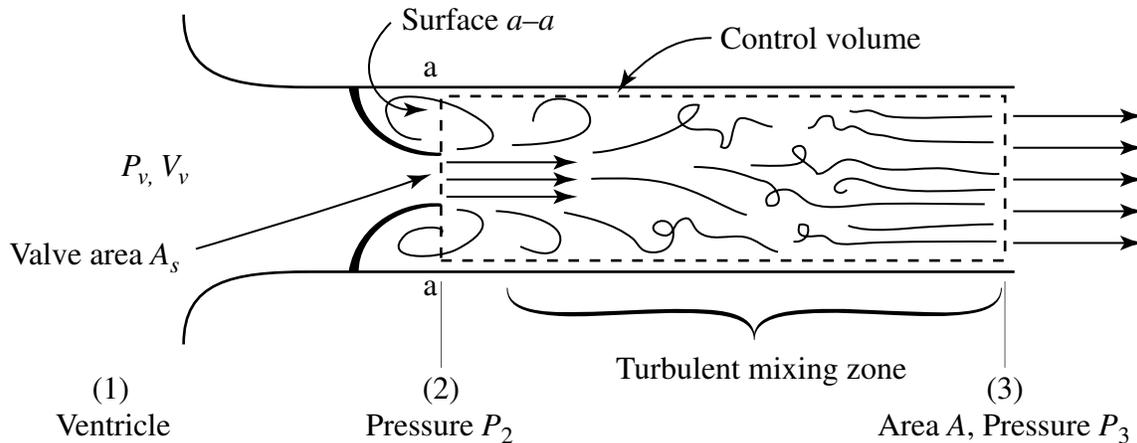
QUIZ 2

SOLUTIONS

Problem 1 (20 min)

One method for determining the degree of flow obstruction produced by a stenosed aortic valve is to measure pressures simultaneously inside the left ventricle and at a point several aortic diameters downstream of the valve. In this question you will be asked to develop the relationship between these pressures and the cross-sectional area of the valve. (See Figure 1.1.)

Figure 1.1:



- A. Find the pressure, P_2 , at the exit of the stenosed valve (2) assuming flow between (1) and (2) to be *inviscid* and *steady*. (Although the real flow is unsteady, the effects of unsteadiness in this calculation are small.) You may express P_2 in terms of the instantaneous flow rate through the valve, Q , the pressure in the ventricle, P_v (where the velocity can be assumed to be zero), the area of the valve, A_s , and the density of blood, ρ .

Use continuity and Bernoulli:

$$P_v + \frac{1}{2}\rho V_v^2 = P_2 + \frac{1}{2}\rho V_2^2$$

but $V_v \approx 0$

$$V_2 = \frac{Q}{A_s}$$

$$P_2 = P_v - \frac{1}{2}\rho \frac{Q^2}{A_s^2}$$

- B. Using the control volume indicated in the sketch, and assuming that the pressure acting all along the upstream surface ($a-a$) is equal to the pressure at (2) calculated in (A), obtain an expression for the pressure difference $P_3 - P_2$. You may assume that both the entering and exit velocity profiles are flat as indicated in the sketch, and that there is vigorous turbulent

mixing between points (2) and (3). Neglect the effects of wall shear stress on the sides of the control volume and of unsteadiness.

Use linear momentum theorem:

$$\begin{aligned}\sum \vec{F} &= P_2 A - P_3 A = (P_2 - P_3) A \\ \frac{d}{dt} \int_{CV} \rho \vec{V} dV &= 0 \quad (\text{steady flow}) \\ \oint_{CS} \rho \vec{V} (\vec{V} \cdot d\vec{A}) &= \rho V_3^2 A - \rho V_2^2 A_s \\ &= \rho Q^2 \left(\frac{1}{A} - \frac{1}{A_s} \right)\end{aligned}$$

So

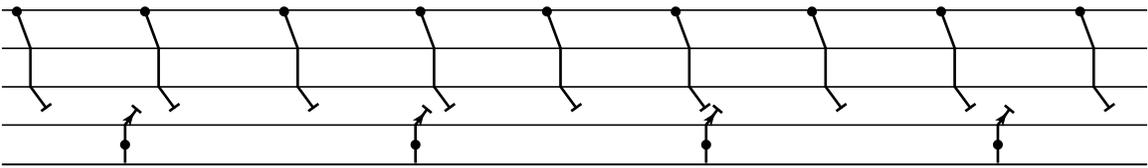
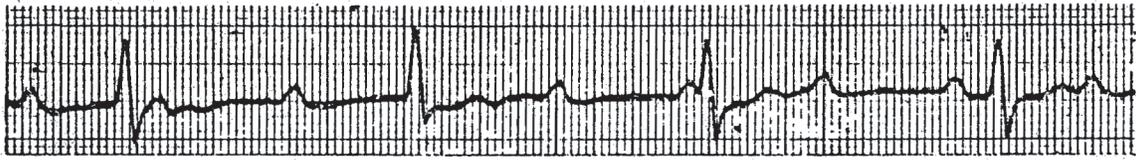
$$P_3 - P_2 = \frac{\rho Q^2}{A} \left(\frac{1}{A_s} - \frac{1}{A} \right)$$

Problem 2 (20 min)

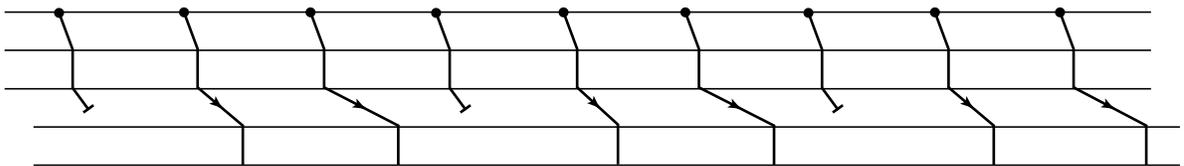
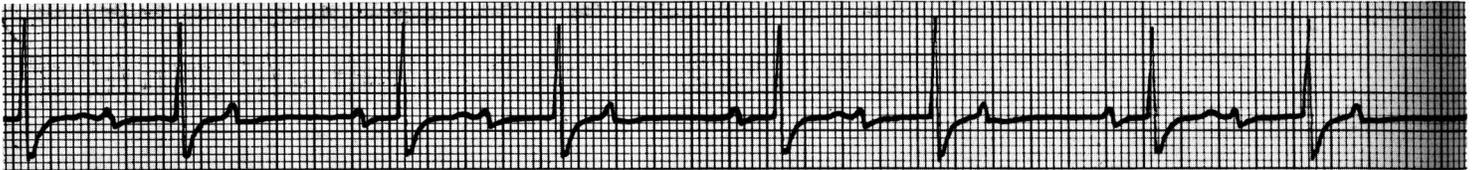
Part I

For each rhythm strip below, identify the rhythm and draw the associated ladder diagram.

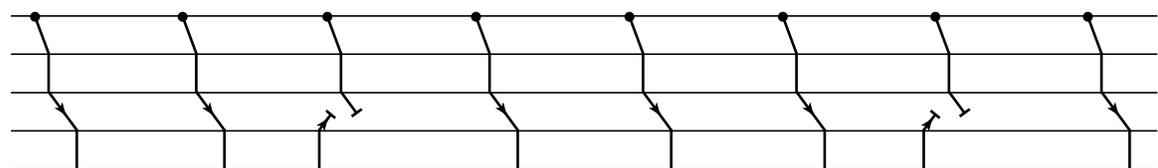
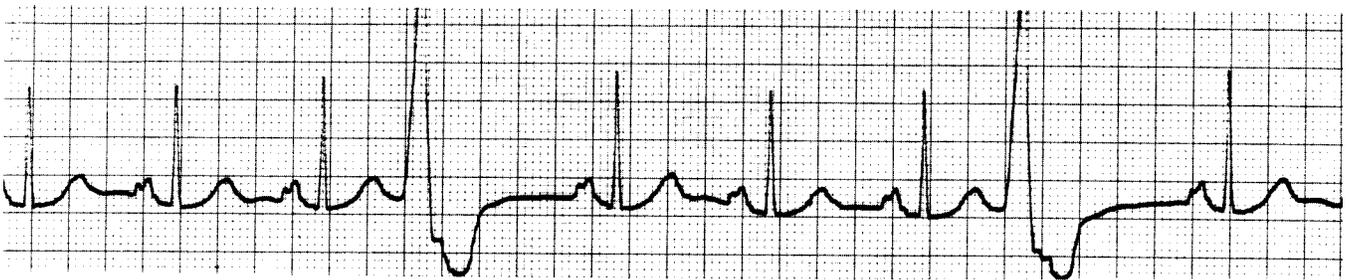
A. Complete heart block with ventricular escape rhythm



B. Second degree AV block (Mobitz I) Wenkebach

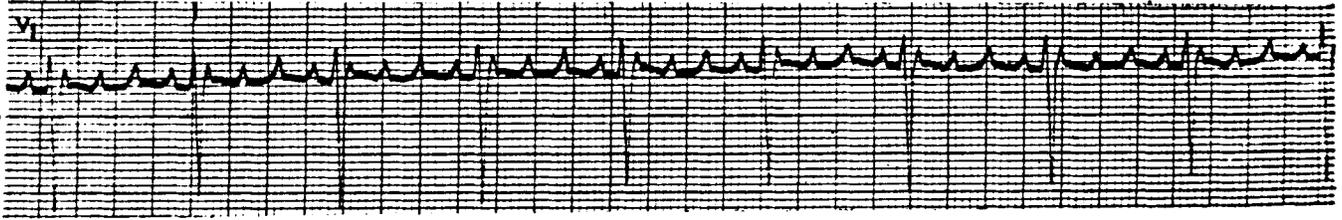


C. Normal sinus rhythm with occasional unifocal PVCs

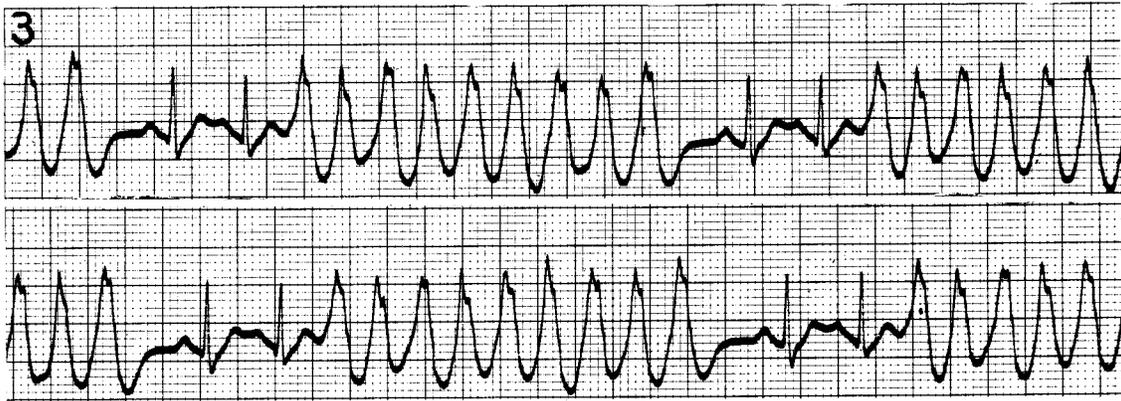


Part II

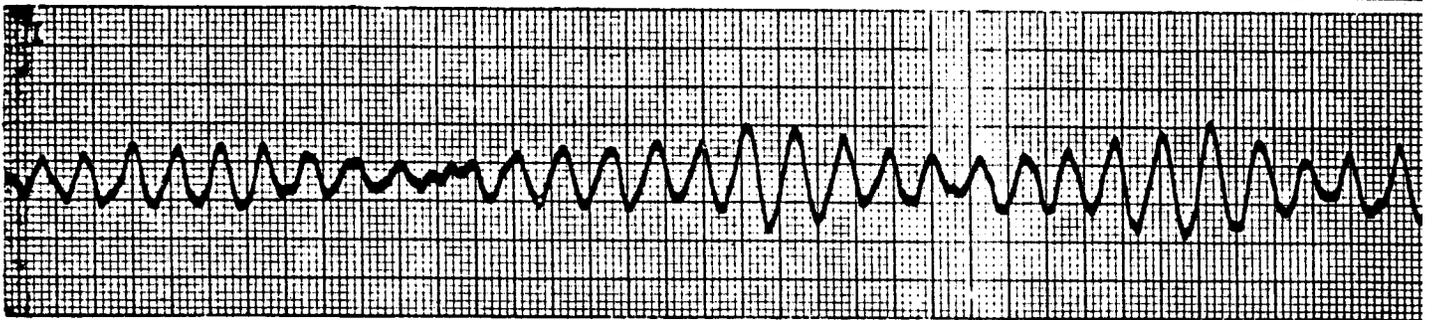
A. Atrial flutter



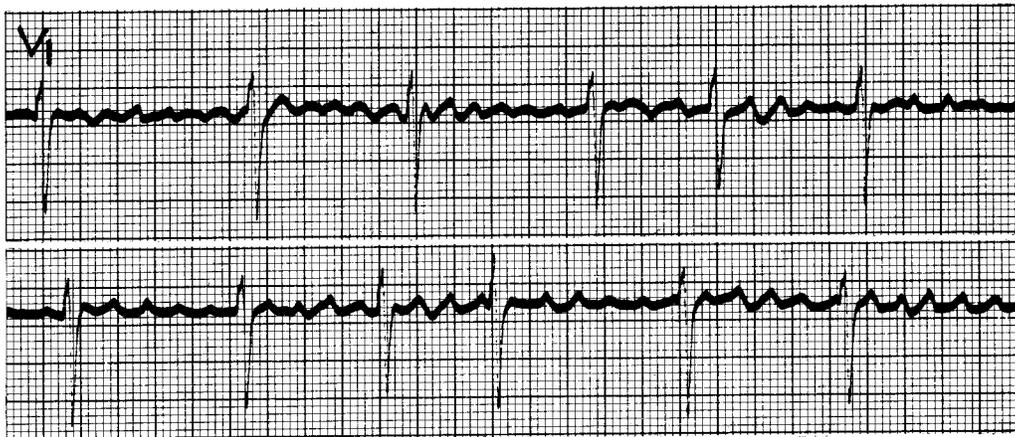
B. Sinus tachycardia with bursts of ventricular tachycardia



C. Ventricular fibrillation



D. Atrial fibrillation, one aberrated beat noted (no. 5, row 1)



Problem 3 (20 min)

Part A

A mammal (e.g. rabbit, dog, etc.) is anesthetized, but has preserved autonomic reflexes. Transducers are placed to record aortic blood flow, aortic blood pressure, and ECG. Continuous calculations and plots are made of HR, mean ABP, and peripheral resistance. Intravenous lines are placed to permit administration of fluid and pharmacologic agents. A balloon catheter is threaded up the inferior vena cava (IVC) to permit transient reduction in venous return when the balloon is inflated. The neck is dissected to expose the carotid arteries, the vagus nerves, and the cervical sympathetic nerves. The aortic nerves are identified and cut between sutures.

A number of experimental procedures are performed as indicated in Table 1 below.

For each experimental procedure, predict the expected responses in HR, BP, and R. Describe your rationale in the space provided, considering both *direct* and *indirect* effects of drugs. For each pharmacologic agent used, include in your rationale the location and type of receptors that are responsible for the *direct* effect of the drug.

Use arrows to indicate responses.

- ↑ Increase
- ↓ Decrease
- No significant change

Table 1:

Intervention	HR	BP	R	Rationale
1. Inject norepinephrine	↓	↑	↑	<i>Stimulates α receptors in arterioles \rightarrow increased resistance and \uparrow BP. Baroreflex drop in HR.</i>
2. Inject isoproterenol (a pure beta agonist)	↑	↓	↓	<i>Stimulates β receptors in heart \rightarrow \uparrow HR and contractility; β receptors in vasculature \rightarrow vasodilation and \downarrow BP (\downarrow resistance). Baroreflex adds to \uparrow HR.</i>
3. Inject acetylcholine	$\downarrow \rightarrow \uparrow$	↓	↓	<i>Triggers endothelium to release NO that causes vasodilation \rightarrow \downarrow R, \downarrow BP, reflex \uparrow HR. (Note: there may be a transient initial drop in HR as a direct effect on SAN.)</i>
4. Inject a beta blocker followed by epinephrine	↓	↑	↑	<i>Blocking β receptors leaves only epinephrine's α stimulation. Thus \uparrow resistance, \uparrow BP, and reflex \downarrow HR.</i>
5. Electrically stimulate the vagus nerve	$\downarrow\downarrow$	↓	↑	<i>Dramatic drop in HR with concomitant drop in BP. Reflex increase in vasoconstriction \rightarrow \uparrow R.</i>
6. Massage the carotid sinus	↓	↓	↓	<i>Massage stimulates baroreceptors \rightarrow reflex reduction in HR, R, and BP.</i>
7. Clamp both carotid arteries	↑	↑	↑	<i>CS senses drop in ABP \rightarrow triggers baroreceptor reflex increase in HR and contractility, \uparrow peripheral resistance and \uparrow BP.</i>
8. Electrically stimulate the distal (heart end) of the aortic nerve	—	—	—	<i>No response since this is an afferent nerve.</i>
9. Inflate a balloon in the IVC to reduce venous return	↑	↓	↑	<i>\downarrow venous return \rightarrow \downarrow C.O. and \downarrow BP. Baroreceptor reflex will \uparrow HR and contractility, and \uparrow R.</i>
10. Electrically stimulate the cervical sympathetic nerve	—	—	\pm	<i>Nerve innervates skin, muscle of face/ears, and pupils. Pupils dilate. Vasoconstriction of ear and face \rightarrow little overall change in R. No change in HR, BP.</i>

Part B

Circle all the correct answers. Treat each choice as a separate true-or-false.

- A. Cardiac output is best increased by stimulation of
- (i) Alpha receptors
 - (ii) Beta receptors
 - (iii) Muscarinic receptors
 - (iv) Both (i) and (iii)
- B. Administration of atropine (it blocks muscarinic acetylcholine receptors) causes
- (i) Increased heart rate
 - (ii) Dilation of the pupils
 - (iii) Decreased heart rate
 - (iv) Constriction of the pupils
- C. Administration of hexamethonium (which blocks nicotinic acetylcholine receptors in autonomic ganglia) to a relaxed subject would result in:
- (i) A drop in blood pressure
 - (ii) An increase in heart rate
 - (iii) A decrease in mean systemic filling pressure, Pms
 - (iv) An increase in both blood pressure and heart rate
- D. Arterial blood pressure is best increased by stimulation of
- (i) Alpha receptors
 - (ii) Beta receptors
 - (iii) Muscarinic acetylcholine receptors
 - (iv) Both (i) and (ii)
- E. The syndrome of postural hypotension (low BP after standing) could be treated by all of the following except:
- (i) Thigh-high elastic stockings
 - (ii) Expansion of blood volume
 - (iii) Beta agonist drugs
 - (iv) Alpha agonist drugs
 - (v) Parasympathetic agonist drugs

F. A patient has a rapid major hemorrhage due to a cut femoral artery. His BP dropped from 120/80 to 80/60. Which of the following physical findings would be expected?

- (i) Pupillary constriction
- (ii) Increased heart rate
- (iii) Bounding full pulse
- (iv) Cool skin
- (v) Flushed face
- (vi) Increased sweating