Series 7 – Solutions

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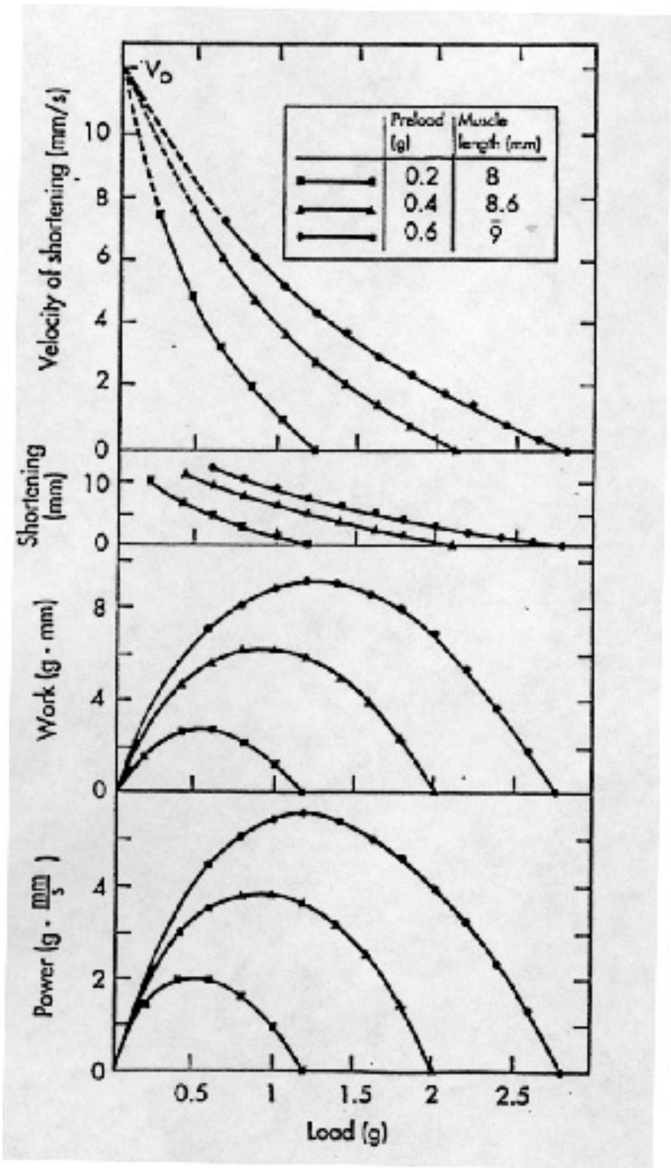
Chapter 12: Cardiac Muscle Mechanics

Exercise 12.1 - Solution

The power, P, developed during contraction is given by P = load · velocity of shortening. The work, W, is given by W = load · shortening. The results are shown in the graph below. Note the bell-shape curves for both power and work. Therefore, for a given preload there is an optimal value of load for which the muscle puts out maximum work and power. Note also the important influence of preload on the work and power furnished by the muscle. The higher the preload the higher the work and power output.



Chapter 13: Pressure-Volume Loop
Exercise 13.1 – Solution

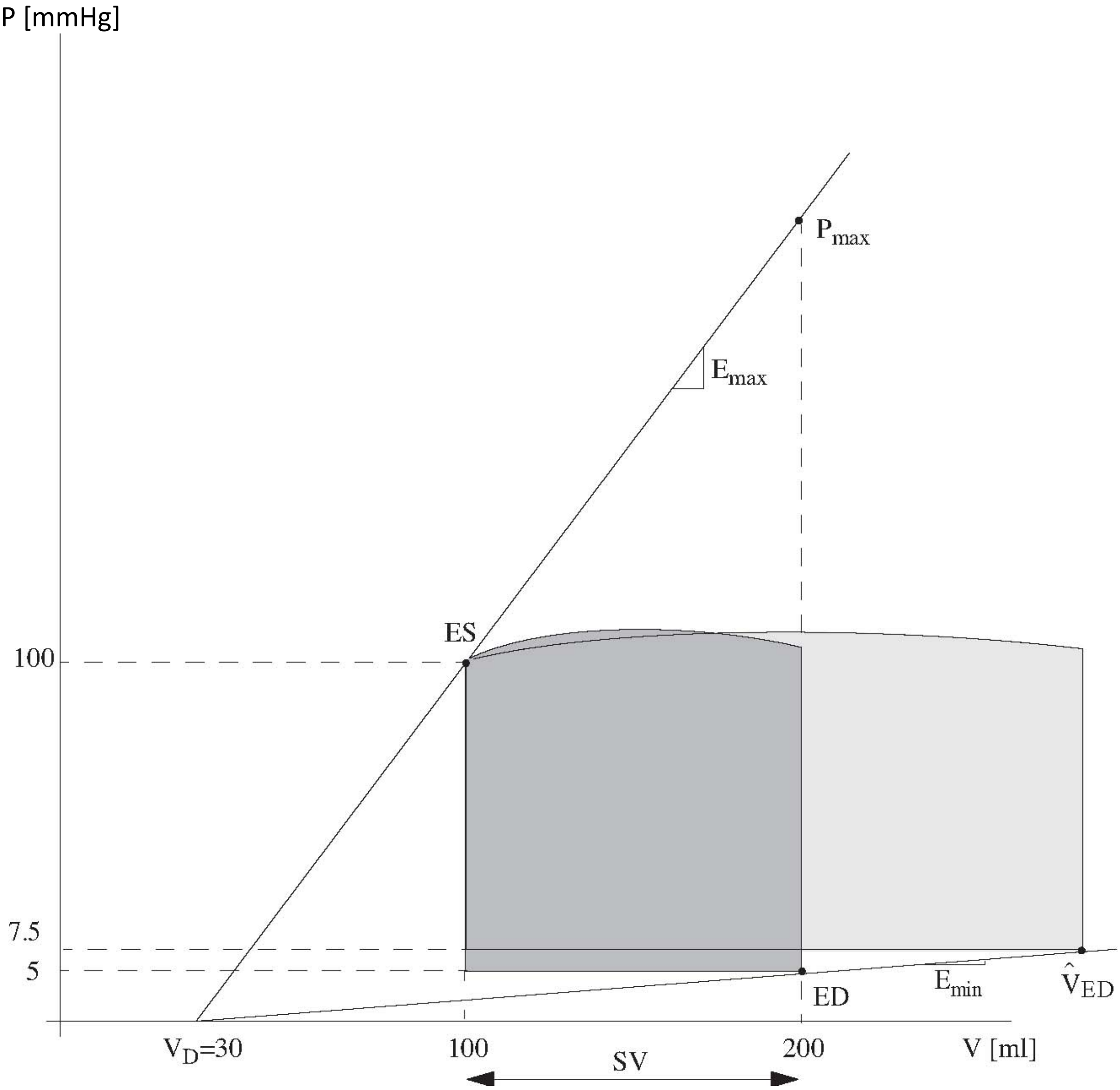


Figure 1. Pressure-volume diagram of left ventricle showing minimum and maximum elastance slopes

a) The minimum elastance, E_{min}, is the slope of the line running from the unloaded condition (zero pressure and dead volume V_D) to the end-diastolic point (P_{ED},V_{ED}) of the pressure-volume diagram of the ventricle:

$$E_{min} = \frac{P_{ED}}{V_{ED} - V_D} = \frac{5}{200-30}\ \frac{\text{mmHg}}{\text{ml}} = 0.0294\ \frac{\text{mmHg}}{\text{ml}} \tag{1}$$

Similarly, the maximum elastance, E_{max}, is defined using the end-systolic point (P_{ES},V_{ES}) by:

$$E_{max} = \frac{P_{ES}}{V_{ES} - V_D} = \frac{100}{100-30} \frac{\text{mmHg}}{\text{ml}} = 1.4286 \frac{\text{mmHg}}{\text{ml}} \quad (2)$$

b) The stroke volume, *SV*, is the blood volume ejected during one stroke:

$$SV = V_{ED} - V_{ES} = (200 - 100) \text{ ml} = 100 \text{ ml} \quad (3)$$

The ejection fraction, *EF*, is the ratio between the stroke volume and the end-diastolic volume (maximum ventricle volume). Thus, applying Eq. (3):

$$EF = \frac{SV}{V_{ED}} = \frac{100 \text{ ml}}{200 \text{ ml}} = 0.5 \quad (4)$$

c) The maximum pressure for an isovolumic non-ejecting beat, P_{max}, can be calculated from the maximum elastance, E_{max}, the dead volume, V_D, and the end-diastolic volume, V_{ED}. During an isovolumic contraction without ejection, the pressure in the ventricle keeps rising while the volume (equal to the end-diastolic volume) remains constant until the maximum elastance is obtained. Thus, we find the function describing the maximum pressure obtainable for the maximum elastance:

$$P_{max}(V) = E_{max}(V-V_D) \quad , \quad \text{for} \quad V > V_D \quad (5)$$

and setting $V = V_{ED}$:

$$P_{max}(V_{ED}) = E_{max}(V_{ED}-V_D) = 1.4286(200\text{-}30) \text{ mmHg} = 242.9 \text{ mmHg} \quad (6)$$

d) A 50% increase in filling pressure results in $\hat{P}_F = 1.5P_F = 1.5 \cdot 5$ mmHg = 7.5 mmHg. We can determine the end-diastolic volume under this new filling pressure, $\hat{V}_{ED}$, in analogy to problem c). We determine the function describing the filling pressure as a function of the minimum elastance and end-diastolic volume:

$$\hat{P}_F(\hat{V}_{ED}) = E_{min}(\hat{V}_{ED}-V_D) \quad , \quad \text{for} \quad \hat{V}_{ED} > V_D \quad (7)$$

Solving Eq. (7) for $\hat{V}_{ED}$ we obtain:

$$\hat{V}_{ED} = V_D + \frac{\hat{P}_F}{E_{min}} = 30 \text{ ml} + \frac{7.5 \text{ mmHg}}{0.0294 \frac{\text{mmHg}}{\text{ml}}} = 285 \text{ ml} \quad (8)$$

The stroke volume under these conditions is:

$$SV = \hat{V}_{ED} - V_{ES} = (285 - 100) \text{ ml} = 185 \text{ ml} \quad (9)$$

The stroke volume thus increases by

$$\frac{SV - SV}{SV} = \frac{\left(185 - 100\right)\ \text{ml}}{100\ \text{ml}} = 85\% \qquad (10)$$

For a 50% increase in filling pressure we gain an 85% increase in ejected blood volume. Thus we can observe that the law of Frank-Starling applies: the increased filling pressure, which is associated with an increased demand for blood elsewhere in the body, results in an increase in stroke volume and thus augmented cardiac output.