Case 11

Ventricular Pressure—Volume Loops

Figure 2-4 shows a pressure-volume loop for the left ventricle. This loop shows the relationship between left ventricular pressure (in mm Hg) and left ventricular volume (in mL) over a single cardiac cycle. Use Figure 2-4 to answer the following questions.

![Figure 2-4](image)

**Figure 2-4** Left ventricular pressure-volume loop. (Adapted with permission from Costanzo LS: *BRS Physiology*, 3rd ed. Baltimore, Lippincott Williams & Wilkins, 2003, p 89.)

### QUESTIONS

1. Describe the events that occur in the four segments between numbered points on the pressure-volume loop (e.g., 1 → 2, 2 → 3). Correlate each segment with events in the cardiac cycle.

2. According to Figure 2-4, what is the value for left ventricular end-diastolic volume? What is the value for end-systolic volume?

3. What is the approximate value for stroke volume? What is the approximate value for ejection fraction?

4. Which portion, or portions, of the pressure-volume loop correspond to diastole? To systole?

5. Which portions of the pressure-volume loop are isovolumetric?

6. At which numbered point does the aortic valve open? At which numbered point does the aortic valve close? At which numbered point does the mitral valve open?

7. At which numbered point, or during which segment, would the first heart sound be heard?
8. At which numbered point, or during which segment, would the second heart sound be heard?

9. Superimpose a new pressure-volume loop to illustrate the effect of an increase in left ventricular end-diastolic volume (i.e., increased preload). What is the effect on stroke volume?

10. Superimpose a new pressure-volume loop to illustrate the effect of an increase in contractility. What is the effect on end-systolic volume? What is the effect on ejection fraction?

11. Superimpose a new pressure-volume loop to illustrate the effect of an increase in aortic pressure (i.e., increased afterload). What is the effect on end-systolic volume? What is the effect on ejection fraction?
2. **End-diastolic volume** is the volume present in the ventricle after filling is complete, but before any blood is ejected into the aorta. Therefore, end-diastolic volume is present at points 1 and 2 (approximately 140 mL). **End-systolic volume** is the volume that remains in the left ventricle after ejection is complete, but before the ventricle fills again (i.e., the volume at points 3 and 4, which is approximately 70 mL).

3. **Stroke volume** is the volume ejected during systole (ventricular ejection). Thus, stroke volume is represented by the width of the pressure-volume loop, or approximately 70 mL (140 mL - 70 mL). **Ejection fraction** is stroke volume expressed as a fraction of end-diastolic volume (i.e., stroke volume/end-diastolic volume), or 70 mL/140 mL, or 0.5 (50%).

4. **Diastole** is the portion of the cardiac cycle when the ventricle is relaxed (i.e., not contracting). Diastole corresponds to segments 3 → 4 (isovolumetric relaxation) and 4 → 1 (ventricular filling). **Systole** is the portion of the cardiac cycle when the ventricle is contracting. Thus, systole corresponds to segments 1 → 2 (isovolumetric contraction) and 2 → 3 (ventricular ejection).

5. By definition, **isovolumetric portions of the ventricular cycle** are those in which ventricular volume is constant (i.e., the ventricle is neither filling with blood nor ejecting blood). Isovolumetric segments are 1 → 2 and 3 → 4.

6. The **aortic valve** opens at point 2, when ventricular pressure exceeds aortic pressure. Opening of the aortic valve is followed immediately by ejection of blood and a decrease in ventricular volume. The aortic valve closes at point 3, and ejection of blood ceases. The **mitral valve** (the atrioventricular valve of the left heart) opens at point 4, and ventricular filling begins.

7. The first heart sound corresponds to closure of the atrioventricular valves. This closure occurs at the end of ventricular filling, at the beginning of isovolumetric contraction. Thus, the first heart sound occurs at point 1.

8. The second heart sound corresponds to closure of the aortic valve, at point 3.

9. **End-diastolic volume** (preload) is the volume of blood contained in the ventricle just before contraction. Therefore, an increase in ventricular end-diastolic volume (e.g., produced by an infusion of saline) means the ventricle has filled to a greater volume during diastole. In Figure 2-5, point 1 shifts to the right to represent the increased end-diastolic volume. The **Frank-Starling relationship** for the ventricle states that the greater the end-diastolic volume, the greater the stroke volume. Therefore, without any change in contractility, an increase in end-diastolic volume causes an increase in stroke volume, as evidenced by increased width of the pressure-volume loop.
10. **Contractility** (inotropy) is the intrinsic ability of myocardial fibers to develop tension at a given muscle length (i.e., at a given end-diastolic volume). Contractility is directly correlated with the **intracellular Ca^{2+}** concentration, which dictates how many cross-bridges cycle and, therefore, how much tension is generated. When contractility is increased (e.g., by positive inotropic agents, such as norepinephrine or digitalis), the ventricle can develop greater tension and pressure during systole. As a result, stroke volume increases (Figure 2-6) and less blood remains in the ventricle after ejection. Therefore, end-systolic volume decreases. Because ejection fraction is stroke volume expressed as a fraction of end-diastolic volume, if stroke volume increases and end-diastolic volume is unchanged, ejection fraction must have increased.

Figure 2-5  Effect of an increase in preload on the left ventricular pressure-volume loop. (Adapted with permission from Costanzo LS: *BRS Physiology*, 3rd ed. Baltimore, Lippincott Williams & Wilkins, 2003, p 90.)

Figure 2-6  Effect of an increase in contractility on the left ventricular pressure-volume loop. (Adapted with permission from Costanzo LS: *BRS Physiology*, 3rd ed. Baltimore, Lippincott Williams & Wilkins, 2003, p 90.)
11. **Afterload** is the pressure against which the ventricles must eject blood. Afterload of the left ventricle is aortic pressure. To open the aortic valve and eject blood, left ventricular pressure must increase to a level greater than aortic pressure. Thus, if afterload increases, the left ventricle must work harder than usual to overcome this higher pressure. Figure 2-7 shows the consequences of an increase in afterload. During isovolumetric contraction (1 → 2) and ventricular ejection (2 → 3), ventricular pressure increases to a higher level than normal. Because of the increased afterload, stroke volume is compromised, more blood remains in the left ventricle after ejection, and end-systolic volume is increased. Because stroke volume decreases and end-diastolic volume is unchanged, ejection fraction must have decreased.

![Figure 2-7](image)

**Figure 2-7** Effect of an increase in afterload on the left ventricular pressure-volume loop. (Adapted with permission from Costanzo LS: BRS Physiology, 3rd ed. Baltimore, Lippincott Williams & Wilkins, 2003, p 90.)
Key topics
Afterload
Aortic valve
Atrioventricular valves
Cardiac cycle
Contractility
Ejection fraction
End-diastolic volume
End-systolic volume
Heart sounds
Mitral valve
Preload
Stroke volume
Ventricular pressure–volume loops