Case 17

Myocardial Infarction: Left Ventricular Failure

Marvin Zimmerman is a 52-year-old construction manager who is significantly overweight. Despite his physician’s repeated admonitions, Marvin ate a rich diet that included red meats and high-calorie desserts. Marvin also enjoyed unwinding with a few beers each evening. He joked with the guys, “I guess I’m a heart attack waiting to happen.” He had occasional chest pains (angina) that were relieved by nitroglycerin.

The evening of his myocardial infarction, Marvin went to bed early because he wasn’t feeling well. He awakened at 2:00 A.M. with crushing pressure in his chest and pain radiating down his left arm that was not relieved by nitroglycerin. He was nauseated and sweating profusely. He also had difficulty breathing (dyspnea), especially when he was recumbent (orthopnea). His breathing was “noisy.” Marvin’s wife called 911, and paramedics arrived promptly and transported him to the nearest hospital.

In the emergency room, Marvin’s blood pressure was 105/80. Inspiratory rales were present, consistent with pulmonary edema, and his skin was cold and clammy. Sequential electrocardiograms and serum levels of cardiac enzymes (creatine phosphokinase and lactate dehydrogenase) suggested a left ventricular wall myocardial infarction. Pulmonary capillary wedge pressure, obtained during cardiac catheterization, was 30 mm Hg (normal, 5 mm Hg). His ejection fraction, measured with two-dimensional echocardiography, was 0.35 (normal, 0.55).

Marvin was transferred to the coronary intensive care unit. He was treated with a thrombolytic agent to prevent another myocardial infarction, digitalis (a positive inotropic agent), and furosemide (a loop diuretic). After 7 days in the hospital, he was sent home on a strict, low-fat, low-Na+ diet.

QUESTIONS

1. Marvin had a left ventricular wall infarction secondary to myocardial ischemia. This damage to the left ventricle compromised its function as a pump; the left ventricle could no longer generate enough pressure to eject blood normally. Draw the normal Frank-Starling relationship for the left ventricle. Superimpose a second curve showing the Frank-Starling relationship after the myocardial infarction, and use this relationship to predict changes in stroke volume and cardiac output.

2. Which information provided in the case tells you that Marvin’s stroke volume was decreased?

3. What is the meaning of Marvin’s decreased ejection fraction?

4. Why was Marvin’s pulmonary capillary wedge pressure increased?

5. Why did pulmonary edema develop? (In your explanation, discuss the Starling forces involved.) Why is pulmonary edema so dangerous?

6. Why did Marvin have dyspnea and orthopnea?

7. Why was Marvin’s skin cold and clammy?

8. What was the rationale for treating Marvin with a positive inotropic agent, such as digitalis? (Hint: See Figure 2–13, which shows the Frank-Starling relationship.)
9. What was the rationale for treating Marvin with furosemide (a loop diuretic)?

10. A medical student in the coronary intensive care unit asked whether Marvin should also be treated with propranolol (a β-adrenergic antagonist). The student reasoned that propranolol would reduce the myocardial O₂ requirement and possibly prevent another infarction. Why does propranolol decrease the myocardial O₂ requirement? The attending physician pointed out that there could be a risk associated with the use of propranolol. What is this risk?

11. Why was Marvin sent home on a low-Na⁺ diet?
1. The **Frank-Starling relationship** for the ventricle states that stroke volume and cardiac output increase with increased ventricular end-diastolic volume (Figure 2-13). Applied to the left ventricle, the volume of blood ejected in systole depends on the volume present in the ventricle at the end of diastolic filling (i.e., preload).

The underlying physiologic principle of the Frank-Starling relationship is the **length-tension relationship for ventricular muscle**. Analogous to the length-tension relationship in skeletal muscle, sarcomere length (which is set by end-diastolic volume) determines the degree of overlap of thick and thin filaments. The degree of overlap determines the possibility of cross-bridge formation and cycling. The number of cross-bridges that actually cycle then depends on the intracellular Ca\(^{2+}\) concentration. Thus, two factors determine how much tension is generated by the ventricle: muscle length (i.e., extent of overlap of thick and thin filaments) and intracellular Ca\(^{2+}\) concentration.

In ventricular failure, contractility decreases and the intrinsic ability of the myocardial fibers to produce tension is impaired; thus, for a given end-diastolic volume, stroke volume and cardiac output are decreased.

![Figure 2-13](image)

**Figure 2-13** Effect of ventricular failure on the Frank-Starling relationship.

2. Several pieces of information are consistent with decreased left ventricular stroke volume, including increased pulmonary capillary wedge pressure (discussed in the answer to Question 4) and decreased ejection fraction (discussed in the answer to Question 3).

However, the most specific information indicating that Marvin's stroke volume was decreased was his decreased pulse pressure. Recall that **pulse pressure** is the difference between systolic and diastolic blood pressure. Marvin's systolic pressure was 105 mm Hg, and his diastolic pressure was 80 mm Hg; therefore, his pulse pressure was only 25 mm Hg. (Normal arterial pressure is 120/80, with a pulse pressure of 40 mm Hg.) Stroke volume is an important determinant of pulse pressure: the blood volume ejected from the ventricle in systole causes arterial pressure to increase from its lowest value (diastolic pressure) to its highest value (systolic pressure). Thus, Marvin's decreased stroke volume resulted in a decreased pulse pressure.
3. Ejection fraction = stroke volume/end-diastolic volume; in other words, ejection fraction is the fraction of the end-diastolic volume that is ejected during systole. Ejection fraction is related to contractility, which is decreased in ventricular failure. Marvin’s stroke volume was only 0.35 (35%) compared with the normal value of 0.55 (55%).

4. Pulmonary capillary wedge pressure is an estimate of left atrial pressure. It is measured by advancing a cannula through the pulmonary artery until it lodges (“wedges”) in its smallest branches. At that point, the cannula senses pulmonary capillary pressure, which is nearly equal to left atrial pressure.

Marvin’s pulmonary capillary wedge pressure was increased because his left atrial pressure was increased. His left atrial pressure was increased secondary to decreased left ventricular stroke volume and ejection fraction. Following ejection, more blood than normal remained behind in the left ventricle; as a result, left ventricular pressure and left atrial pressure both increased.

5. The decrease in left ventricular ejection fraction caused blood to “back up” in the left side of the heart, increasing left ventricular and left atrial pressures. The increase in left atrial pressure led to increased pulmonary venous pressure. The increase in pulmonary venous pressure led to increased pulmonary capillary hydrostatic pressure (P_t), which is the major Starling force favoring filtration of fluid into the pulmonary interstitium (see Case 16 and Figure 2-12).

When the filtration of fluid exceeded the capacity of Marvin’s pulmonary lymphatics to remove the fluid, pulmonary edema occurred. Initially, the excess fluid accumulated in the interstitial space, but eventually, it also “flooded” the alveoli.

Pulmonary edema is dangerous because it compromises gas exchange in the lungs. This discussion is more the venue of pulmonary physiology. Briefly, though, pulmonary edema increases the diffusion distance for O_2. When the diffusion distance increases, there is decreased diffusion of O_2 from alveolar gas into pulmonary capillary blood. In addition, pulmonary blood flow is shunted away from alveoli that are filled with fluid rather than with air (i.e., hypoxic vasoconstriction). As a result, there is impaired oxygenation of pulmonary capillary blood, which causes hypoxemia (decreased P_{O_2} of arterial blood). Hypoxemia is an important cause of hypoxia (decreased O_2 delivery to the tissues).

6. If you are a first-year medical student, you may need to look up the terms “dyspnea” and “orthopnea.”

Dyspnea is the sensation of difficult breathing. The etiology of dyspnea in pulmonary edema is not entirely clear, but the following factors play a role: (1) Juxtacapillary (J) receptors are stimulated by the accumulation of interstitial fluid, and trigger reflexes that stimulate rapid, shallow breathing. (2) Bronchial congestion stimulates the production of mucus. As a result, resistance of the bronchi is increased, causing wheezing and respiratory distress (called “cardiac asthma,” referring to the left ventricular failure that produced the pulmonary edema). (3) Accumulation of edema fluid leads to decreased pulmonary compliance, which increases the work of breathing.

Orthopnea is dyspnea that is precipitated by lying down. When a person lies down, venous return from the lower extremities back to the heart is increased. In left ventricular failure, increased venous return compounds the pulmonary venous congestion that is already present.

7. Marvin’s skin was cold and clammy because the stress of the myocardial infarction produced a massive outpouring of catecholamines (epinephrine and norepinephrine) from the adrenal medulla. The circulating catecholamines activated α₁-adrenergic receptors in cutaneous vascular beds and reduced cutaneous blood flow.

8. As already discussed, damage to the left ventricle (secondary to the myocardial infarction) led to decreased contractility, decreased stroke volume, and decreased cardiac output for a given end-diastolic volume. Consider the Frank-Starling relationships that you constructed for Question 1. The curve for ventricular failure is lower than the curve for a normal ventricle, reflecting
decreased contractility, stroke volume, and cardiac output. Positive inotropic agents, such as digitalis, increase contractility by increasing intracellular Ca²⁺ concentration. Digitalis was expected to increase contractility and return the Frank-Starling relationship toward that seen in a normal ventricle.

9. One of the most dangerous aspects of Marvin's condition was the increased pulmonary venous pressure that caused his pulmonary edema. (As already discussed, the cardiac output of the left ventricle was impaired, and blood backed up into the pulmonary veins.) Therefore, one therapeutic strategy was to reduce venous blood volume by reducing extracellular fluid volume. Loop diuretics, such as furosemide, are potent inhibitors of Na⁺ reabsorption in the renal thick ascending limb; when Na⁺ reabsorption is inhibited, Na⁺ excretion increases. The resulting decrease in extracellular Na⁺ content leads to decreased extracellular fluid volume and blood volume.

10. Propranolol, a β-adrenergic antagonist, reduces myocardial O₂ requirement by blocking β₁ receptors in the sinoatrial node and ventricular muscle. Normally, these β₁ receptors mediate increases in heart rate and contractility, which increase cardiac output. Cardiac output is part of the "work" of the heart, and this work requires O₂. Therefore, antagonizing β₁ receptors with propranolol decreases heart rate, contractility, cardiac output, and myocardial O₂ consumption.

Perhaps you’ve anticipated a potential risk in treating Marvin with a β-adrenergic antagonist. Propranolol could further decrease his already compromised cardiac output, thus should be given cautiously.

11. Extracellular fluid volume is determined by extracellular Na⁺ content. A low-Na⁺ diet was recommended to reduce extracellular fluid volume and blood volume, and to prevent subsequent episodes of pulmonary edema (similar to the idea of treating Marvin with a diuretic).

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**Key topics**

- β-Adrenergic antagonist
- Contractility
- Cutaneous blood flow
- Digitalis, or cardiac glycosides
- Dyspnea
- Ejection fraction
- Frank-Starling relationship
- Furosemide
- Hypoxemia
- Hypoxia
- Left heart failure
- Left ventricular failure
- Loop diuretics
- Orthopnea
- Positive inotropism
- Propranolol
- Pulmonary capillary wedge pressure
- Pulmonary edema
- Pulse pressure
- Starling forces