

Cardiac Output

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Page 1. Introduction

- Cardiac output is the amount of blood pumped out by each ventricle in one minute.
- Cardiac output can increase markedly to meet the demands placed on our body, whether dashing to catch a bus or riding a mountain bike,

Page 2. Goals

- To recognize that cardiac output varies directly with heart rate and stroke volume.
- To identify factors that modify heart rate and stroke volume, and to indicate how they change cardiac output.

Page 3. Cardiac Output Definition

- Cardiac Output (CO) = The volume of blood ejected from the left or right ventricle into the aorta or pulmonary trunk per minute.
- Cardiac output depends on: 1. Heart rate 2. Stroke volume

$$\begin{array}{ccccccc} \text{Cardiac Output} & = & \text{Heart Rate} & \times & \text{Stroke Volume} \\ \text{CO} & = & \text{HR} & \times & \text{SV} \end{array}$$

Page 4. Heart Rate Definition

- Heart rate (HR) is the number of times the heart beats in one minute, averaging 75 beats per minute (bpm) in the adult at rest.

Page 5. Stroke Volume Definition

- Stroke volume (SV) is the amount of blood pumped by each ventricle with each heartbeat, averaging 70 ml per beat in the adult at rest.

Page 6. SV = EDV - ESV

- Stroke volume represents the difference between end diastolic volume (EDV) and end systolic volume (ESV).
- By the time diastole ends, each ventricle has filled up with blood. This amount of blood is the **end diastolic volume** or EDV.
- The amount of blood ejected during the systole is the stroke volume. At the end of systole the volume of blood remaining in each ventricle is the **end systolic volume** or ESV.
- Each ventricle normally contains about 120 ml of blood by the end of diastole. At the end of systole about 50 ml of blood are left in each ventricle. This means that 70 ml of blood were pumped out of each ventricle during systole.

$$\begin{array}{ccccccc} \text{Stroke Volume} & = & \text{End-Diastolic Volume} & - & \text{End-Systolic Volume} \\ \text{SV} & = & \text{EDV} & - & \text{ESV} \\ \sim 70 \text{ ml/beat} & = & \sim 120 \text{ ml/beat} & - & \sim 50 \text{ ml/beat} \end{array}$$

Page 7. Cardiac Output Demonstration

** Let this animation run for a full minute until it is done. This will give you some appreciation for the amount of blood that is pumped each minute by the heart at rest - about 5.25 liters!

** Now is a good time to go to quiz question 1:
• Click the Quiz button on the left side of the screen.

- After answering question 1a and 1b, click the Back to Topic button on the left side of the screen.
- To get back to where you left off, click on the scrolling page list at the top of the screen and choose "8. Regulation of Cardiac Output".

Page 8. Regulation of Cardiac Output

- The key factor regulating stroke volume is the amount of stretching that occurs to ventricular cardiac muscle prior to ventricular contraction. The more cardiac muscle stretches, the more forcefully it contracts. These stronger contractions increase stroke volume.

** Please note, there is a lot of important information on this page. Go through this page slowly and try to make sense of it.

- Fill out this chart, making note of the reasons for the increase or decrease:

	Affect on Heart Rate	Affect on Stroke Volume	Affect on Cardiac Output
Increased Sympathetic Stimulation			
Increased Parasympathetic Stimulation			
Increased Venous Return			
Slow Heart Rate			
Extremely Fast Heart Rate			
Exercise			
Sudden Drop in Blood Pressure			
Rising Blood Pressure			
Sudden Drop in Blood Volume			
Excess Calcium			

- **Increased Sympathetic Stimulation** - Increased sympathetic stimulation (due to fright, anger, etc.) increases the heart rate. It also increases stroke volume by increasing contractility, which results in more complete ejection of blood from the heart (lower ESV).

- **Increased Parasympathetic Stimulation** - Parasympathetic activity increases after a crisis has passed. This reduces heart rate and stroke volume from their high levels, bringing cardiac output back to normal.
- **Increased Venous Return** - Cardiac muscle fibers are stretched by increased blood volume returning to the heart (increased venous return and EDV). Increased stretch results in greater force of contraction, which increases stroke volume.
- **Slow Heart Rate** - Slow heart rate allows for more time for ventricular filling, increasing EDV and therefore stroke volume.
- **Extremely Fast Heart Rate** - Extremely rapid heart rate results in low venous return and therefore decreased stroke volume.
- **Exercise** - Exercise activates the sympathetic nervous system, increasing heart rate, contractility, and stroke volume. Both the higher heart rate and squeezing action of skeletal muscles on veins increase venous return, contributing to increased stroke volume.
- **Sudden Drop in Blood Pressure** - A sudden drop in blood pressure results in low venous return and therefore decreased stroke volume. However heart rate increased due to sympathetic activity, and normal cardiac output is maintained.
- **Rising Blood Pressure** - Rising blood pressure reduces sympathetic activity, decreasing heart rate. High blood pressure also increases arterial pressure which ventricles must overcome before semilunar valves open, increasing ESV and decreasing stroke volume. Reduced cardiac output helps bring blood pressure down to normal levels.
- **Sudden Drop in Blood Volume** - A sudden drop in blood volume (eg. due to severe blood loss) results in low venous return and therefore decreased stroke volume. Sympathetic activity increases heart rate, maintaining cardiac output.
- **Excess Calcium** - Excess calcium can lead to spastic heart contractions, an undesirable condition. Calcium also increases stroke volume by enhancing contractility.

Page 9. Heart Videos

- Effect of Epinephrine on a Frog's Heart:
Epinephrine is normally released when there is increased sympathetic activity.
- Effect of Acetyl Choline on a Frog's Heart:
Acetyl choline is a parasympathetic neurotransmitter.

Page 10. Summary

- Cardiac Output = Heart Rate X Stroke Volume
- Heart rate is increased by sympathetic nerve activity and epinephrine. Heart rate is decreased by parasympathetic nerve activity.

** Now is a good time to go to quiz questions 2 and 3:

- Click the Quiz button on the left side of the screen.
- Click on the scrolling page list at the top of the screen and choose "2. Heart Rate Regulation".
- Work through quiz questions 2-3.

Notes on Quiz Questions:

Quiz Question #1a: Cardiac Output

- This question asks you to calculate cardiac output based on stroke volume and heart rate. If you get stuck, remember the equation:

$$\text{Cardiac Output} = \text{Heart Rate} \times \text{Stroke Volume}$$

Also remember that there are 1000 milliliters in 1 liter.

Quiz Question #1b: Soda Bottles

- This question asks you to illustrate the cardiac output.

Quiz Question #2: Heart Rate Regulation

- This question asks you to predict what will happen to heart rate in various situations.

Quiz Question #3: Stroke Volume Regulation

- This question asks you to predict what will happen to stroke volume in various situations.

Study Questions on Cardiac Output:

1. (Page 3.) Define cardiac output.
2. (Page 3.) What two factors does cardiac output depend on?
3. (Page 3.) What is the mathematical relationship between cardiac output, heart rate, and stroke volume.
4. (Page 4.) Define heart rate.
5. (Page 4.) What is the average heart rate in an adult at rest?
6. (Page 5.) Define stroke volume.
7. (Page 5.) What is the average stroke volume in an adult at rest?
8. (Page 6.) Define end diastolic volume.
9. (Page 6.) Define end systolic volume.
10. (Page 10.) What is the mathematical relationship between end diastolic volume, end systolic volume, and stroke volume?
11. (Page 6.) If the ESV is 50 ml and the EDV is 120 ml, what is the stroke volume?
12. (Page 7.) If the heart rate is 75 beats per minute and the stroke volume is 70 ml per beat, then what is the cardiac output?
13. (Page 8.) What's the relationship between cardiac muscle stretch and force of contraction? What effect does this have on stroke volume?
14. (Page 8.) What's the relationship between venous return and stroke volume?
15. (Page 8.) What is the effect of increased sympathetic activity on heart rate and stroke volume? How does this effect cardiac output?
16. (Page 8.) What is the effect of increased parasympathetic activity on heart rate and stroke volume?
17. (Page 8.) What is the effect of increased venous return on heart rate and stroke volume? How does this effect cardiac output?
18. (Page 8.) What effect does a slow heart rate have on stroke volume?
19. (Page 8.) What effect does a fast heart rate have on stroke volume?

20. (Page 8.) What is the effect of exercise on heart rate and stroke volume? How does this effect cardiac output?
21. (Page 8.) What is the relationship between blood pressure and sympathetic activity? What effect does this have on heart rate?
22. (Page 8.) What is the effect of a sudden decrease in blood pressure on heart rate and stroke volume?
23. (Page 8.) What is the effect of a sudden increase in blood pressure on heart rate?
24. (Page 8.) What is the effect of a sudden increase in blood pressure on stroke volume?
25. (Page 8.) What is the effect of a sudden drop in blood volume on heart rate and stroke volume?
26. (Page 8.) What is the effect of an increase in calcium on heart rate and stroke volume?