Exercise, Vascular Function, and Control

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Redistribution of Blood Flow

Exercise, especially vigorous aerobic exercise, requires not only an increase in blood flow (aka cardiac output) but the redistribution of that blood flow to meet the increased oxygen demand of the exercise.

This is accomplished by a complex interaction of the autonomic nervous system, metabolic, hormonal, and other factors.
Cardiovascular Control During Exercise

Rapid responses (seconds)

When exercise begins, and even before, central command stimulates the CV control center (fight or flight response)
Cardiovascular Control During Exercise

In any activity involving the rhythmic contraction of the leg muscles (walking, running, cycling) the skeletal muscle pump increases blood flow by facilitating venous return.
Cardiovascular Control During Exercise
The two “competing” branches of the Autonomic Nervous System

Parasympathetic
Dominant at rest and where exercise HR < 110 bpm
- Decreases HR
- Decreases contractility
- Decreases cardiac output

Sympathetic
- Increases HR
- Increases contractility
- Decreases blood flow to gut, kidneys, skin, muscle etc. (vasoconstriction) to increase blood pressure
- Stimulates release of epinephrine from adrenal glands
Cardiovascular Control During Exercise

Neural regulation of the cardiovascular system during exercise:

- **Autonomic nervous system:** *efferent regulation: from central nervous system to heart and muscle:*

  Parasympathetic nervous system
Cardiovascular Control During Exercise

Sympathetic nervous system:

- Stimulates release of catecholamines: epinephrine/adrenaline and norepinephrine/noradrenaline from adrenal glands.

Catecholamines increase HR and contractility and mobilize fuels for energy production.
Type III muscle afferents (aka mechanoreceptors) are stimulated by muscle contraction send signals to the CV Control Center in the brainstem (medulla oblongata) to increase HR, BP, and cardiac output.
Cardiovascular Control During Exercise

The baroreceptor set-point is raised

Figure 1. Location and innervation of arterial baroreceptors.
Cardiovascular Control During Exercise

Slower responses (seconds to minutes)

Local changes in metabolism (accumulation of metabolic by-products) stimulate muscle blood flow in TWO important ways.
Type IV receptors (aka metaboreceptors) are sensitive to increases in CO$_2$, pH (lactic acid), adenosine, K$^+$ and other metabolites produced during exercise.

These receptors also send signals to the CV Control Center to increase sympathetic activity, HR, contractility, BP, and cardiac output.
During exercise, these same metabolites are the dominant regulators of muscle blood flow via their direct effect on vascular smooth muscle (and NOT nitric oxide).
Collectively, signals from the Type III and Type IV muscle afferents is called the *Pressor reflex*.

The Pressor reflex and the resulting increases in heart rate and blood pressure are directly proportional to:

The relative intensity of muscle contraction

The muscle mass involved
Cardiovascular Control During Exercise

Slower responses, cont.

- Release of catecholamines, especially epinephrine (adrenaline) from the adrenal glands serves to further increase HR, contractility, BP, and cardiac output.

- Norepinephrine and epinephrine also mobilize fuels for energy production.
Cardiovascular Control During Exercise

The hypothalamus is stimulated by increased temperature and increases blood flow to the skin to facilitate cooling resulting in less blood available to the exercising muscles.
As exercise intensity increases, the activity of Type III and IV muscle afferents increases and signals from central command, CVC, hypothalamus, baroreceptors, chemoreceptors, and muscle afferents are balanced.
What about blood flow to other organs?

Blood flow to the brain is also determined by metabolic activity, chiefly CO$_2$.

Given the lungs are normally very effective at maintaining arterial CO$_2$ at about 40 mmHg, even during vigorous exercise, blood flow to the brain is also relatively constant.
What about blood flow to other organs?

Blood flow to the kidneys is also relatively constant thanks to the myogenic response. Vascular smooth muscle is inherently responsive to transmural pressure in maintaining constant blood flow.
What are the factors that influence cardiac output and muscle blood flow during exercise?
Factors affecting cardiac output during exercise

Frank-Starling Principle states:

Cardiac output is determined by 4 factors:

- Preload
- Afterload (SBP)
- Contractility
- Heart rate
Factors affecting cardiac output during exercise:

Preload
(end diastolic volume)

Preload refers to the amount of blood returning to the heart. The Frank-Starling principle states that the amount of blood pumped from the heart (cardiac output) is directly dependent on the amount of blood received or returned to the heart.
Determinants of Preload

a) Posture

Blood returning to the heart has to work against gravity. If you are in a supine position (i.e., swimming) then venous return will be increased.
Determinants of Preload

b) Blood volume


c) Skeletal muscle pump

Contraction of skeletal muscle literally pumps blood through the veins. Valves in the veins insure unidirectional flow.
Determinants of Preload

d) Intrathoracic pressure
The movement of the chest associated with the increased ventilation during exercise facilitates venous return. (Same principle as skeletal muscle pump)

e) Medications
Nitrates (i.e., nitroglycerine) decrease venous return. This is the mechanism by which they reduce the workload on the heart and attenuate chest pain (angina).
Determinants of Afterload

Afterload refers to the pressure that the left ventricle must overcome to pump blood through the arteries. Essentially this is arterial pressure (SBP).

a) Sympathetic/parasympathetic input (see discussion)
Determinants of Afterload

a) Sympathetic/parasympathetic input
   (see discussion above)
Determinants of Afterload

b) Muscle contractions

The harder the active muscles contract, the greater the mechanical pressure they exert on the blood vessels. This increases resistance and, therefore, intra-muscular pressure. The heart must then work harder to overcome this pressure to supply blood (perfuse) to the active muscles.
Determinants of Afterload

c) Vascular function

A healthy blood vessel favors vasodilation while persons with hypertension have poor vaso-motor function and greater peripheral resistance.
d) Medications, specifically anti-hypertensive drugs, decrease afterload/blood pressure by differing mechanisms.
Factors Affecting Cardiac Output: Myocardial Contractility

a) **Condition of the myocardium**
   
   In individuals with coronary artery disease (CAD) there may be a real (myocardial infarction) or functional (myocardial ischemia) loss of heart muscle.
Factors Affecting Cardiac Output: Myocardial Contractility

b) Medications

Beta blockers and calcium channel blockers can reduce stress on the heart by decreasing contractility. Digitalis increases contractility.

c) Length-Tension relation

Unlike skeletal muscle, the force of contraction produced by cardiac muscle increases continually as it is stretched.
Length-Tension Relation

Skeletal Muscle

Cardiac Muscle
Factors Affecting Cardiac Output: Myocardial Contractility

The length/tension produced is directly dependent on preload. That is, the more blood in the ventricles the more they will be stretched. Individuals with congestive heart failure, for example, lose this ability to produce greater force with increasing tension.

e) Sympathetic/parasympathetic input  
   (see discussion above)
Factors Affecting Cardiac Output

4) Heart rate

a) Sympathetic/parasympathetic input (see discussion above)

b) Medications

Drugs such as beta-blockers will reduce heart rate response to exercise
Factors Affecting Cardiac Output

5) Synergy of contraction
   Is the heart beating as a well-coordinated unit?

a) Arrhythmias
   Individuals with arrhythmias have compromised coronary function because the heart is not working as a unit. Individuals with underlying CAD are more likely to experience life-threatening arrhythmias.

![ECG](image-url)
Factors Affecting Cardiac Output

6) Compliance of ventricles
   How stretchable or compliant are the major chambers of the heart?

   Defined as $\triangle \text{ volume} / \triangle \text{ pressure}$

   a) Aging decreases the compliance of the ventricles

   b) Loss of viable myocardium not only decreases contractility but compliance as well
Factors Affecting Cardiac Output

7) Exercise Training

a) Increase in left ventricular volume (LVV)

Aerobic training increases the size of left ventricle. Specifically, it increases the size of the chamber itself, not the myocardium. Weight lifting, on the other hand, also increases the size of the left ventricle but it is the myocardium itself that enlarges.
Effect of Exercise Training on Cardiac Output and Vascular Function

b) Blood volume
Aerobic training increases blood volume.

c) Contractility and Compliance
There is strong evidence that aerobic training increases myocardial contractility while the effect on compliance remains equivocal.
Effects of Exercise Training on Cardiac Output and Vascular Function

d) Cardiac efficiency

Endurance training, especially, has been shown to result in improved Ca\(^{2+}\) cycling and reduced O\(_2\) demand.
Nitric oxide (NO) is produced by vascular endothelium in response to the increased shear stress produced by the increased blood flow resulting from exercise.
Effects of Exercise Training on Vascular Function

Increased shear stress associated with dynamic exercise results in increased production of NO, improved vasomotor function and vascular remodeling.
QUESTIONS???