



Physiological changes of exercise

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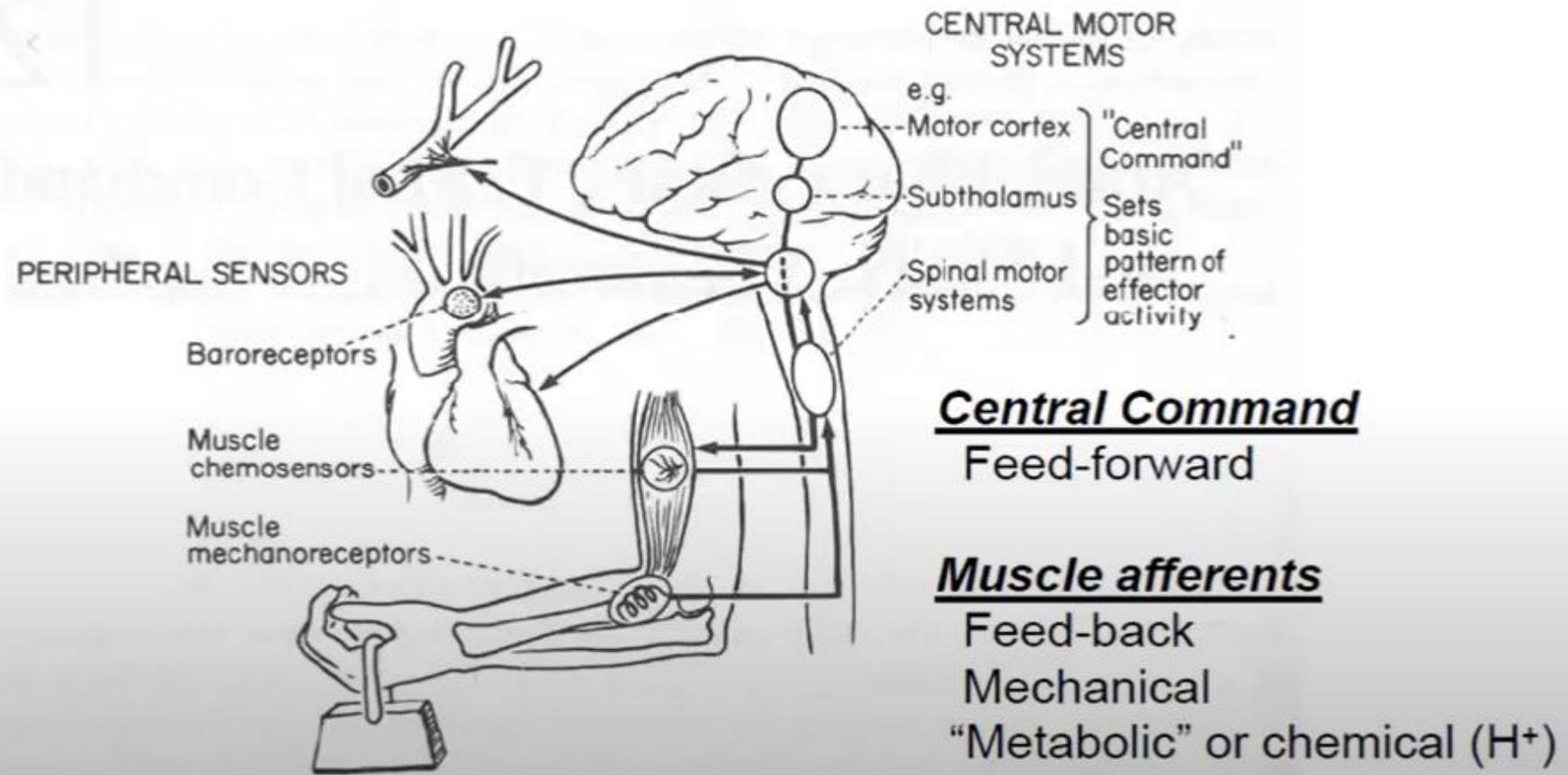
OUTLINE

- 1. Physiologic Changes of Exercise**
 - A. Venous Return
 - B. Contractility
 - C. Systemic Vascular Resistance
 - D. Afterload
 - E. Heart Rate
 - F. Coronary Perfusion
 - G. Minute Ventilation
 - H. Temperature
 - I. Blood pH
- 2. Rate of Oxygen Consumption in Exercise**
 - A. Fick Principle
 - B. Oxygen Extraction Efficiency
- 3. Cardiac Output in Athletes**
 - A. General principles
 - B. Athletic Cardiovascular Physiology

Physiologic Changes of Exercise

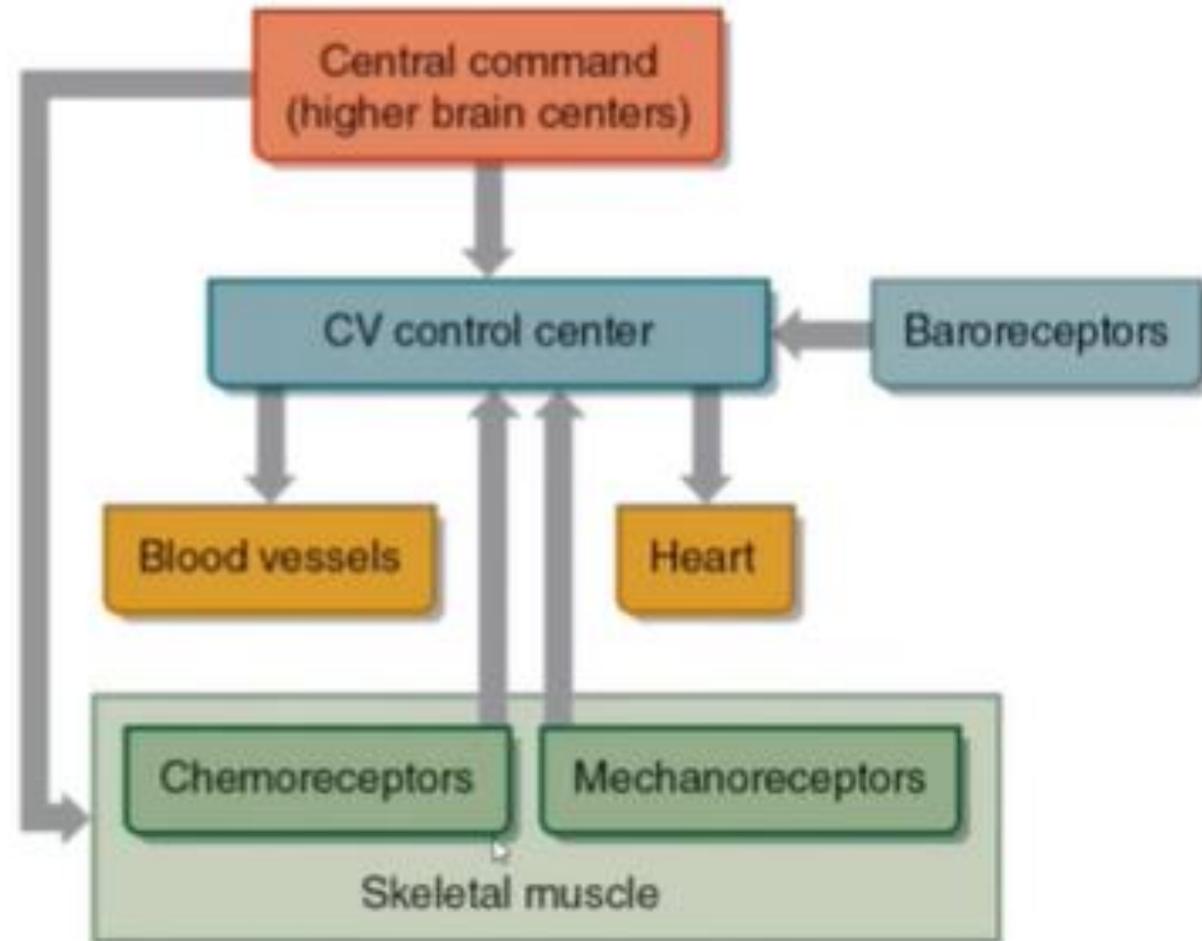
- **↑ Preload**
 - Venoconstriction → ↑ venous return → ↑ LVEDV
 - Vasoconstriction of splanchnic vessels
 - Vasodilation at skeletal muscle → ↓ SVR (↓ DBP)
- **↑ Contractility**
- **↑ Afterload**
 - ↑ LV and aortic pressure in systole > ↓ SVR (↓ DBP)
- **↑ Heart Rate**
 - ↑ Sympathetic tone (withdrawal of vagal tone)
- **↓ Coronary Perfusion**
 - Decreased time spent in diastole at high heart rates
- **↑ Minute Ventilation**
 - ↑ O₂ demand → ↑RR, ↑TV → ↑O₂ consumption and CO₂ production
- **↑ Temperature**
- **↓ Arterial pH**
 - ↑ Lactic acidosis

How is the cardiovascular system regulated during exercise?



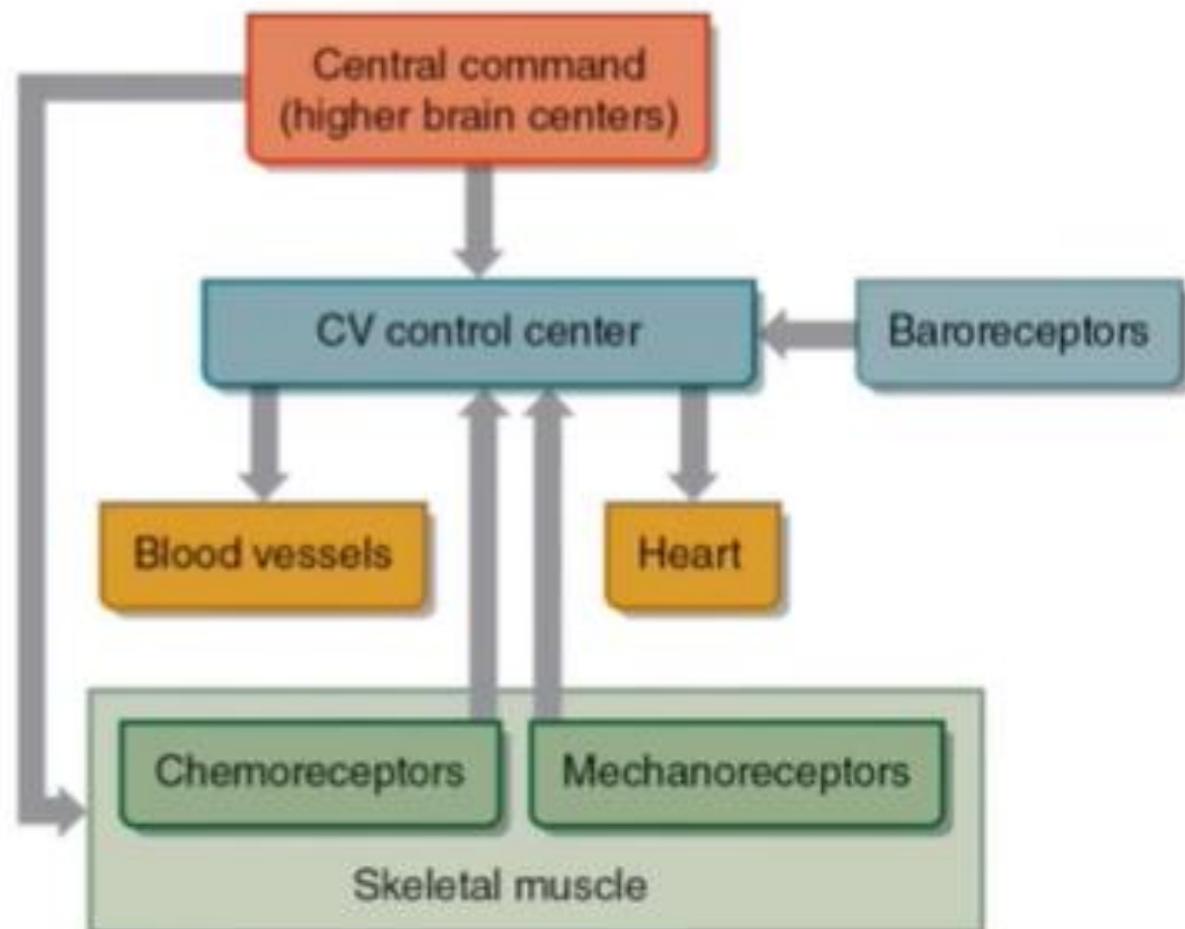
Central command

- Simultaneous activation of motor and cardiovascular centers
- Resets BP set-point
- 4 primary components
 - Hypothalamus
 - Baroreceptors
 - Chemoreceptors
 - Muscle afferents



Central command

- Hypothalamus
 - Alters circulation due to temperature changes
- Baroreceptors
 - Increases BP setpoint during exercise
- Chemoreceptors
 - Monitor PO_2 , PCO_2 and pH
- Muscle afferents
 - Type III, IV afferent respond to mechanical, thermal and chemical stimuli
 - Most active during intense exercise
 - Minimizes amount of local vasodilation



Oxygen Delivery During Exercise

- **Oxygen demand by muscles during exercise is 15–25x greater than at rest**
- **Increased O₂ delivery accomplished by:**
 - Increased cardiac output
 - Redistribution of blood flow
 - From inactive organs to working skeletal muscle

Stroke Volume Does Not Plateau in Endurance Athletes

- **Stroke volume reaches a plateau at 40–60% VO_2 max in untrained subjects**
 - At high HR, filling time is decreased
 - Decrease in EDV and SV
- **Stroke volume does not plateau in trained subjects**
 - Improved ventricular filling
 - Increase in EDV and SV at high HR

ENDURANCE ATHLETE

MAX HR: 170 BPM

SV: 150 ML PER BEAT

CO = $170 \times 150 = 25,500$ ML PER MIN

CO = 25.5 L PER MIN

SEDENTARY

$170 \times 90 = 15,300$ ML PER MIN

15.3 L PER MIN

SEDENTARY

RESTING HEART RATE: 70 BPM

CO = HR x SV

CO = 70 BPM x 70 ML BLOOD PER BEAT

ENDURANCE ATHLETE

RESTING HEART RATE: 50 BPM

STROKE VOLUME: 100ML PER BEAT

CO = HR x SV

CO = 50 BPM x 100 ML BLOOD

CO = 5000 ML BLOOD PER MINUTE

Redistribution of Blood Flow During Exercise

- **Increased blood flow to working skeletal muscle**
 - At rest, 15–20% of cardiac output to muscle
 - Increases to 80–85% during maximal exercise
- **Decreased blood flow to less active organs**
 - Liver, kidneys, GI tract
- **Redistribution depends on metabolic rate**
 - Exercise intensity

Regulation of Local Blood Flow During Exercise

- **Skeletal muscle vasodilation**
 - Autoregulation
 - Blood flow increased to meet metabolic demands of tissue
 - Due to changes in O_2 tension, CO_2 tension, nitric oxide, potassium, adenosine, and pH
- **Vasoconstriction to visceral organs and inactive tissues**
 - SNS vasoconstriction

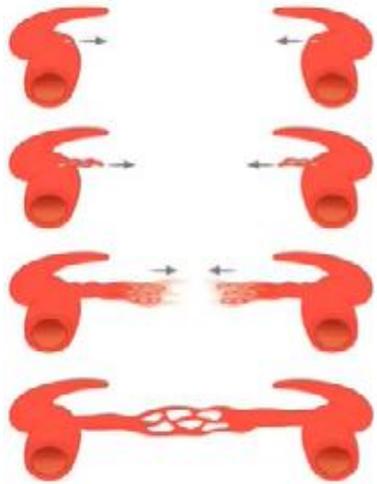
Nitric Oxide Is an Important Vasodilator

- **Produced in the endothelium or arterioles**
- **Promotes smooth muscle relaxation**
 - Results in vasodilation and increased blood flow
- **Important in autoregulation**
 - With other local factors
- **One of several factors involved in blood flow regulation during exercise**
 - Increases muscle blood flow

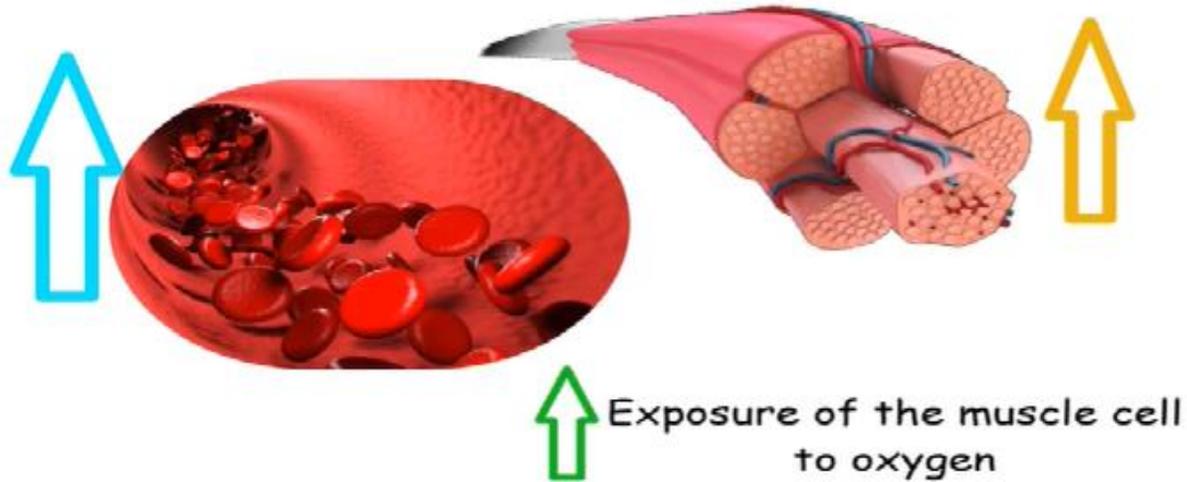
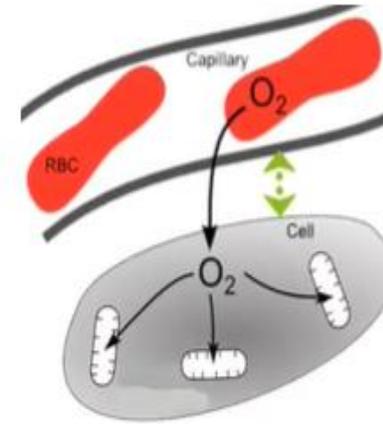
How does exercise training increase the arteriovenous oxygen difference?

Angiogenesis

The growth of new blood vessels



as much as a **60%** increase in the number of capillaries surrounding a skeletal muscle cell as compared to before exercise training



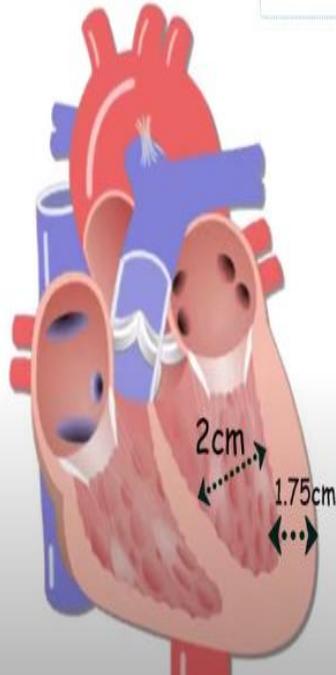
Exercise training

Increases the amount of oxygen in the blood,
increases the exposure time of the oxygen to the cells,
decreases the distance the oxygen must travel to reach the cell
and increases the rate at which oxygen can enter the cells

$$VO_{2max} = HR_{max} \times SV_{max} \times \Delta_{arteriovenous} O_2 \text{ conte}$$

Pathological hypertrophy

$$= 2/1.75$$
$$= 1.14$$



Ventricular chamber radius
Wall thickness

$$= 2/1$$
$$= 2$$

Physiologic hypertrophy

VO_{2max} The maximal amount of oxygen consumed in one minute

The Fick equation $VO_{2max} = HR_{max} \times SV_{max} \times \Delta$ arteriovenous O₂ content

In Summary

- Oxygen delivery to exercising skeletal muscle increases due to (1) an increased cardiac output and (2) a redistribution of blood flow from inactive organs to the contracting skeletal muscle.
- Cardiac output increases as a linear function of oxygen uptake during exercise. During exercise in the upright position, stroke volume reaches a plateau at approximately 40% of $\dot{V}O_2$ max; therefore, at work rates above 40% $\dot{V}O_2$ max, the rise in cardiac output is due to increases in heart rate alone.

In Summary

- During exercise, blood flow to contracting muscle is increased, and blood flow to less-active tissues is reduced.
- Regulation of muscle blood flow during exercise is primarily regulated by local factors (called autoregulation). Autoregulation refers to intrinsic control of blood flow by changes in local metabolites (e.g., oxygen tension, pH, potassium, adenosine, and nitric oxide) around arterioles.