Muscle adaptation to exercise

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Objective

- Strength, power, and endurance of muscles
- Effect of athletic training on muscles and muscle performance
- Muscle hypertrophy
- Fast-twitch and slow-twitch muscle fibers
- Respiration in exercise
- Oxygen consumption and pulmonary ventilation in exercise
- Effect of training on vo_2 max
- Cardiovascular system in exercise
- Work output, oxygen consumption, and cardiac output during exercise
- Effect of training on heart hypertrophy and on cardiac output
- Role of stroke volume and heart rate in increasing the cardiac output
- Body heat in exercise & heatstroke

Strength, Power, And Endurance Of Muscles

- Muscles Strength(force) :_Refers to the amount of force a muscle can produce
- A maximal contractile force, Normally 3 -4 kg/cm^2 (Size of muscles influence)
- E.g a cross-sectional area 150 cm^2 cause maximal contractile strength of about 525 kilograms
- Mechanical work of muscle =
- force applied by the muscle X distance

Muscle Strength

Muscle strength has mechanical & neural components :

(1) Mechanical strength (force)

-the maximum force a muscle can exert.

This depends upon the muscle cross-sectional area .

So if after a period of training, an athlete increases his muscle size by 50 % , he will also increase the force the muscle can develop by 50%

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(2) Neurological strength : meaning how many of the anterior horn cells(AHC)motor neurons of the spinal cord supplying that muscle are recruited + frequency of action potentials in them to supply the muscle.

In diseases involving the AHCs (e.g., poliomyelitis) the number of active AHCs may be considerably reduced → decreased muscle performance.

A severely depressed person (or athlete) , who lost his motivation , may , unconsciously , recruit less AHCs than normal → decreased performance

Muscle Power

When muscles contract or stretch in moving a load they do **work** , and energy is transferred from one form to another.

The " **power** " of muscles refers to how quickly the muscles can do this work and transfer the energy.

Work = Force X Distance

Power = Work/Time

The shorter the time used to perform a piece of work , the more power is needed
Hence , if a weightlifter lifts a given weight explosively over a short time (say 0.5 seconds) he needs his muscles to produce much more power than if he did that while taking more time (say 3 sec).

Strength, Power, And Endurance Of Muscles

- **Muscles Power :** amount of work that the muscle performs in period of time (kg-m/min)
- -**Power = Work/Time**

	kg-m/min
First 8 to 10 seconds	7000
Next 1 minute	4000
Next 30 minutes	1700

Guyton & Hall12E

Endurance Of Muscles

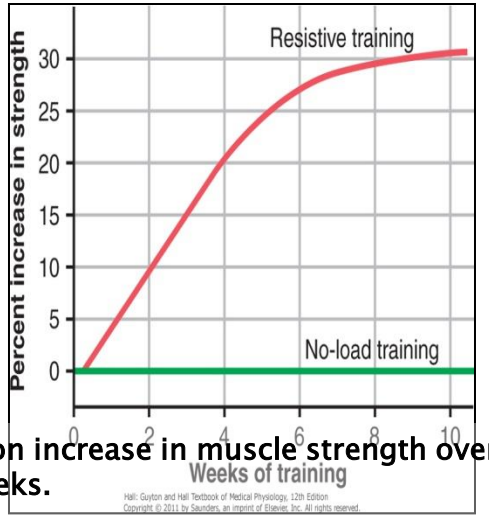
- Muscles Endurance: Ability of muscles to sustain repeated contractions against a resistance for period of time.
- depends on glycogen stored in the muscle

Effect of Training on Muscles and Muscle Performance

- Maximal Resistance Training:
- 6 maximal muscle contractions sets against a load X 3 days X one week greatly increase in muscle strength, without muscle fatigue.
- –10 weeks training increase strength 30%

However !!!!

- Muscles function under no load cause little increase in strength



Approximate effect of optimal resistive exercise training on increase in muscle strength over a training period of 10 weeks.

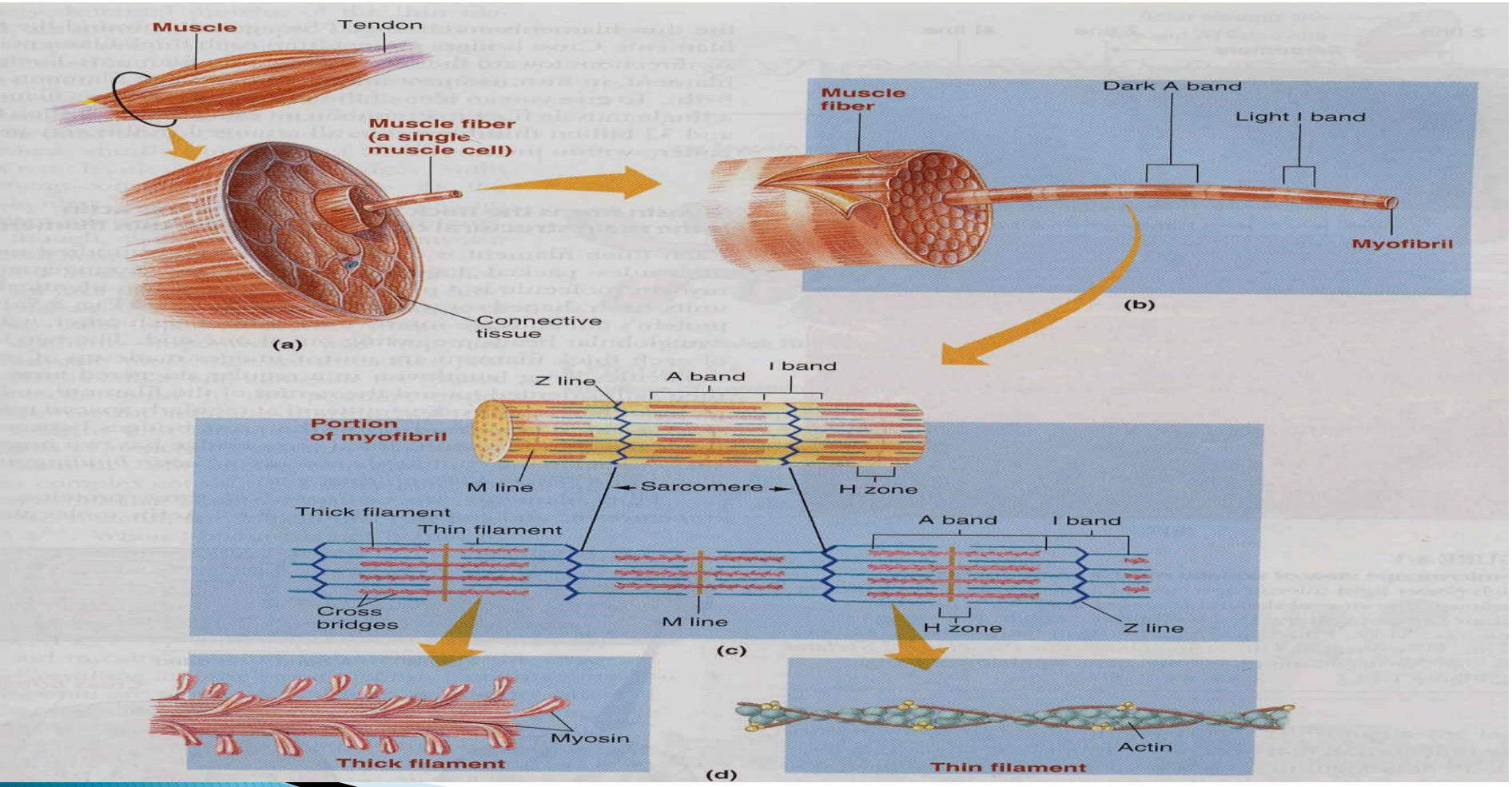
Muscle Hypertrophy:

- With training muscles hypertrophied 30- 60 %
- Due to ↑diameter of the muscle fibers more than the
- number of fibers
- Changes in hypertrophied muscle:
- ↑myofibrils
- ↑120 % in mitochondrial enzymes
- ↑ ATP and phosphocreatine
- ↑50 % in stored glycogen
- ↑75 -100 % in stored triglyceride
- ↑oxidation rate 45 %
- Increased capability of aerobic and anaerobic metabolic systems

Muscle Hypertrophy

EXCERCISE hypertrophy is due to increase in contractile protein (number of actin &myosin filaments in each muscle fibre = muscle cell).

-When number of contractile proteins increases sufficiently, myofibrils split within each muscle fibre to form new myofibrils, so it is mainly great increase in the number of additional myofibrils that causes muscle fiber to hypertrophy.
That is, hypertrophy results primarily from the growth of each muscle cell, rather than an increase in the number of cells.


Muscle
Tendon
Muscle fiber (a single muscle cell)
Connective tissue
(a)
Muscle fiber
Dark A band
Light I band
Myofibril
(b)
Z line
A band
I band
Portion of myofibril
M line
Sarcomere
H zone
Thick filament
Thin filament
Cross bridges
M line
A band
I band
H zone
Z line
(c)
Myosin
Thick filament
Actin
Thin filament
(d)

Each muscle is composed of combination of 2 types of muscle fibers but one is usually dominant

1-Anaerobic ("fast-twitch")

- White muscle fibers(deficient in myoglobin)
-larger in size for strong& powerful contraction
-have extensive sarcoplasmic reticulum for rapid release of calcium
-have a lot of glycolytic enzymes for rapid release of energy
-lower capillarity& few mitochondria because oxidative metabolism is of secondary importance

2-Aerobic ("slow-twitch")

- Red muscle fibers because its high content of myoglobin
-Smaller & innervated with small nerve fibers & they are adapted for prolonged muscle activity
-have extensive sarcoplasmic reticulum for rapid release of calcium
-have a lot of glycolytic enzymes for rapid release of energy
-Higher capillarity& large number of mitochondria to support high level of oxidative metabolism

Fast-Twitch and Slow-Twitch Muscle Fibers

- **fast-twitch fibers**: forceful and rapid contraction

E.G gastrocnemius muscle

- **slow-twitch muscle**: for prolonged muscle activity

E.G leg muscle

fast-twitch fibers deliver power from seconds to a minute

slow-twitch fibers provide endurance, prolonged strength of contraction minutes to hours.

!!! differences between the fast-twitch and the slow-twitch fibers Read Guyton & Hall: Textbook of Medical Physiology 12E

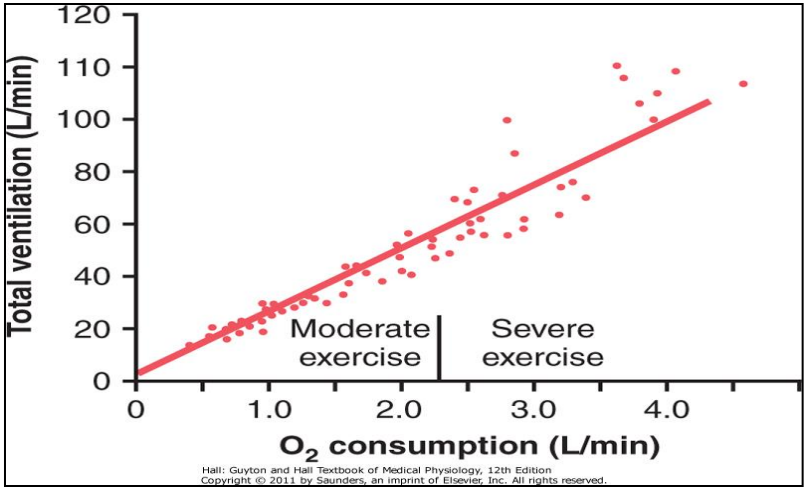
Respiration In Exercise

- **Oxygen Consumption VO_2 and Pulmonary Ventilation VE in Exercise**
- **VO_2** at rest is about 250 ml/min , However !!! at Maximal efforts

	ml/min
Untrained average male	3600
Athletically trained average male	4000
Male marathon runner	5100

VO2 and **VE** increase about 20-folds between the resting state and maximal intensity(untrained)

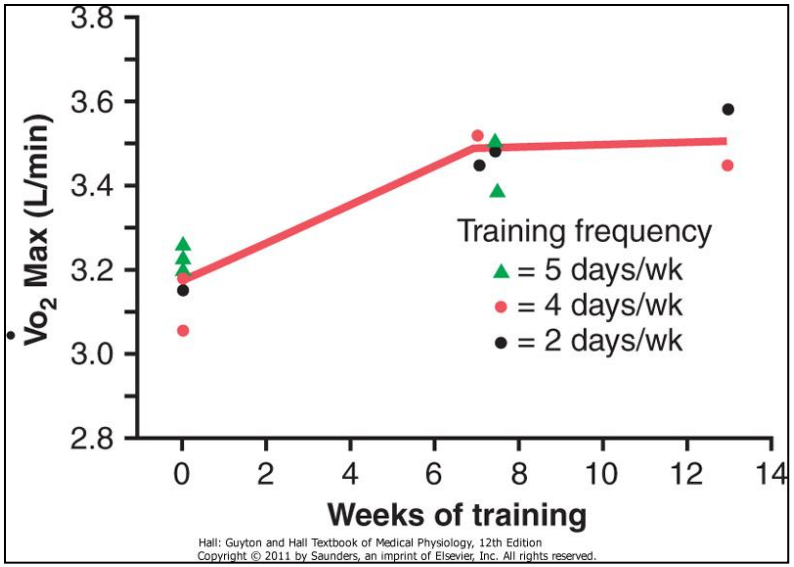
-Maximal breathing capacity of an athlet can reach during maximal exercise 50% more than actual pulmonary ventilation



F Effect of exercise on oxygen consumption and ventilatory rate. (Redrawn from Gray JS: Pulmonary Ventilation and Its Physiological Regulation. Springfield, Ill: Charles C Thomas, 1950.)

Effect of Training on Vo_2 Max

- Vo_2Max increased only about 10 percent by training, Moreover other factors !!!
- Chest sizes in relation to body size
- Increase respiratory muscles force of contraction



Increase in Vo2 Max over a period of 7 to 13 weeks of athletic training. (Redrawn from Fox EL: Sports Physiology. Philadelphia: Saunders College Publishing, 1979.)

O2 diffusion capacityi ncreases 3 folds during exercise than at rest due to:-

1-increase of lung blood flow in pulmonary capillaries during exercise , this increases surface area for O2 to diffuse into pulmonary capillaries.

2- Respiration is stimulated by neurogenic mechanisms due to direct stimulation of respiratory center by nervous signals that also transmitted from brain to muscle to do exercise, sensory signals also transmitted from contracting muscle and moving joints into respiratory center to stimulate respiration , so blood gases during exercise are normal in concentration(no increase in Co2 or decrease in O2 as expected)

Cardiovascular System in Exercise

- Cardiac output (CO) = stroke volume (SV) X heart rate (HR)
- Muscle blood flow increases 25% folds during sternous exercise

- Work Output, Oxygen Consumption, and Cardiac Output During Exercise
- all these are directly related to one another, muscle work output increases oxygen consumption, and increased oxygen consumption in turn dilates the muscle blood vessels, thus increasing venous return and cardiac output.

- Effect of Training on Heart Hypertrophy and on Cardiac Output:
- Training increase C.O about 40 % greater than untrained persons SO,
- heart chambers of marathoners enlarge about 40 percent in contrast to non trained
- Heart size of marathoner larger than normal person

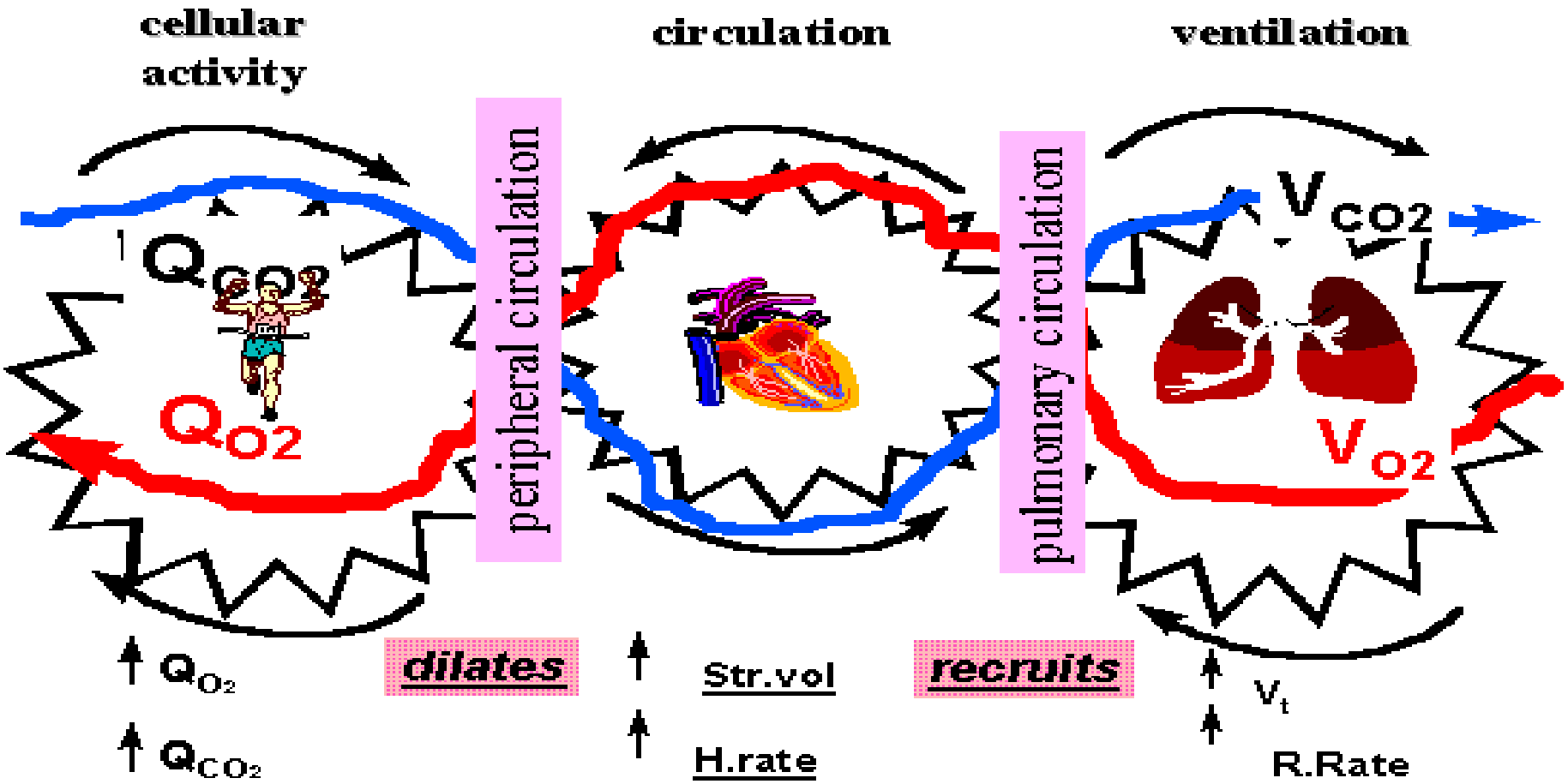
Comparison of Cardiac Function Between Marathoner and Nonathlete

	Stroke Volume (ml)	Heart Rate (beats/min)
Resting		
Nonathlete	75	75
Marathoner	105	50
Maximum		
Nonathlete	110	195
Marathoner	162	185

Guyton & Hall: Textbook of Medical Physiology 12E

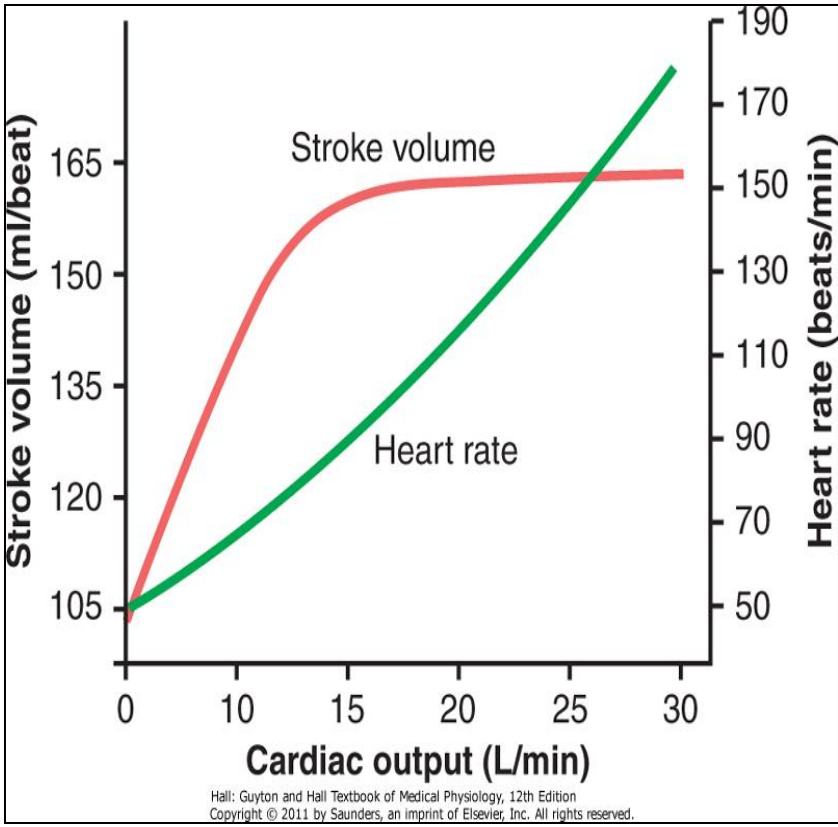
Cardiovascular System in Exercise cont…

- Role of Stroke Volume and Heart Rate in Increasing the Cardiac Output



Cardiovascular System in Exercise cont…

- the cardiac output increases from its resting level of about 5.5 L/min to 30 L/min.
- The stroke volume increases from 105 to 162 milliliters, an increase of about 50 percent
- whereas the heart rate increases from 50 to 185 beats/min, an increase of 270 percent.
- the heart rate increase a greater proportion of the increase in cardiac output than does the increase in stroke volume



Approximate stroke volume output and heart rate at different levels of cardiac output in a marathon athlete.

Body Heat In Exercise

- Almost all the energy released by the body's metabolism converted into body heat.
- Muscle work use only 20 – 25 % of energy released from metabolism.
- remainder converted into heat as result of :
- (1) resistance to the movement of the muscles and joints,
- (2) friction of the blood flowing through the blood vessels, and
- (3) muscle contractile converted into heat.

Heatstroke

- During endurance training body temperature rises (37° to 40°C)
- hot and humid conditions body temperature rise (41° to 42°C)
- Consequently, temperature destructive tissue cells mainly (brain cells) and symptoms are :
- Body weakness, exhaustion, headache, dizziness, nausea (disgust), sweating, confusion, uncontrolled gait, collapse, and unconsciousness.
- And may lead to death

Treatment of heatstroke

The most practical way :

- Remove all clothing
- Maintain a spray of cool water on all surfaces of the body or continually sponge the body.
- Blow air over the body with a fan.
- Physicians prefer total immersion of the body in water containing a mush of crushed ice if available.

Reference book

Guyton & Hall: Textbook of Medical Physiology 12E


Thank you !