9 Muscle Adaptation To Exercise

- Very important
- Extra information
- Terms

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Objectives

- Strength, power, and endurance of muscles
- The 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

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Definitions

Muscle Strength	The amount of force a muscle can produce
Muscle Power	A measure of the total amount of work that the muscle performs in a unit period of time (kg-m/min)
Muscle Endurance	The ability of muscles to sustain repeated contractions against a resistance for period of time
VO_2 max (Oxygen Consumption)	The rate of oxygen usage under maximal aerobic metabolism.
Oxygen-Diffusing Capacity	A measure of the rate at which oxygen can diffuse from the pulmonary alveoli into the blood.

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Strength of Muscles

- Muscles Strength (force) :Refers to the amount of force a muscle can produce.

- **Maximal contractile of the muscle is determined by the following :**

Equation: Cross-sectional area × 3-4 kg/cm2 "size of muscle influence"
= Maximal Muscle Strength

Mechanical work of muscle= Force applied by the muscle X distance

Example:

- cross-sectional area = 150 cm^2
- contractile force = 3.5 kg/cm^2 (for each 1cm^2 of fiber)
- maximal muscle strength= ??

Equation: 150 cm^2 × 3.5 kg/cm2 = 525 kg

*The maximal muscle strength= 525 kg

Also it is known as The maximal overload of this muscle.

Muscle strength = muscle force = "قوة العضلة تتناسب طردياً مع حجم العضلة " كلما زاد حجم العضلة كلما زادت قوتها

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Strength of Muscles

- **Muscle strength has mechanical and neural components :**

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 wil also increase the force the muscle can develop by 50%

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 (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

- Neurological strength : by increasing the recruitment of motor neurons and nerve impulses "firing rate". If someone has a disease in AHC such as poliomyelitis "شلل الأطفال" virus will destruct the AHC in the anterior horn of spinal cord and complete damage will occur to these neurons which make the patient unable for recruitment of motor neurons.

Muscle Power

- **Work :**

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

Work = Force **X** Distance

- **Power :** Refers to how quickly the muscles can do this work and transfer the energy.

Power = Work **/** Time

{ The shorter the **time** used to perform a piece of work ,the more **power** is needed }

Example

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).

Muscle power : work divided by time
Work = Force x distance > power = Force x distance / Time
العلاقة بين الـpowerوالزمن عكسية, كلما زاد الزمن كلما قلت الـ power
مثال : لاعب يحمل ثقل لمدة 3 ثوان , ولاعب آخر يحمل ثقل لمدة دقيقة أيهما تكون لديهpower أكثر ؟

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Muscle Power

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

Power = Work / Time

"as we mentioned"

- The maximal power achievable by all the muscles in the body of a highly trained athlete with all the muscles working together to produce a power is presenting in the following table :

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

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Endurance of Muscles

- **Muscles Endurance:**
  Ability of muscles to sustain repeated contractions against a resistance for period of time.

- The Endurance of the muscle Depends on the glycogen stored in the muscle.

- Endurance is enhanced by a high-CHO diet. "النظام الغذائي الغني بالكربوهيدرات"

	Minutes
High-carbohydrate diet	240
Mixed diet	120
High-fat diet	85

The corresponding amounts of glycogen stored in the muscle before the race started explain these differences. The amounts stored are approximately the following:

	g/kg Muscle
High-carbohydrate diet	40
Mixed diet	20
High-fat diet	6

- Endurance Of Muscles :

قوة تحمل العضلة وتعتمد على كمية الجلايكوجين المخزن فيها فكلما زادت كمية الجلايكوجين كلما زادت قابلية العضلة للتحمل والمقاومة

- Against resistance:

مثل تمارين المقاومة "استخدام أثقال" تزيد من قوة تحمل العضلة اعتماداً على كمية الجلايكوجين أما التمارين الهوائية "مثل الجري" لا تتطلب مقاومة بالتالي لا تعمل على تقوية العضلات بالمقدار الكافي مثل تمارين المقاومة.

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Muscle Performance

- ## Maximal Resistance Training:

6 maximal muscle contractions performed in three sets **3** days a week greatly increase in : muscle strength and muscle mass (muscle hypertrophy) without muscle fatigue.

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

With training muscles hypertrophied 30- 60 % Due to ↑ diameter of the muscle fibers , and ↑ number of fibers
10 weeks training increase strength 30%

Muscles function under no load ↑ little in strength .

* Two factors affecting Muscle Performance:

1) Heredity
2) Testosterone secretion.

لو صرت تشيل أثقال 6 مرات باليوم على فترات متتالية لمدة 3 أيام في الأسبوع بالتالي راح تزيد قوة عضلاتك بدون مايصير لها شد عضلي ولما تستمر على نفس المنوال لمدة 10 أسابيع قوتك العضلية راح تزيد بمقدار 30%!

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Changes in hypertrophied muscle fiber

- ↑ myofibrils
- ↑ 45 % oxidation rate
- ↑ capability of aerobic and anaerobic metabolic systems
- ↑ 50 % in stored glycogen
- ↑ 60-80% in phosphagen metabolic system
- ↑ 75 -100 % in stored triglyceride
- ↑ 120% in mitochondrial enzymes
- ↑ ATP and phosphocreatine

*Dr. M. ALOTAIBI said : It's very important slide

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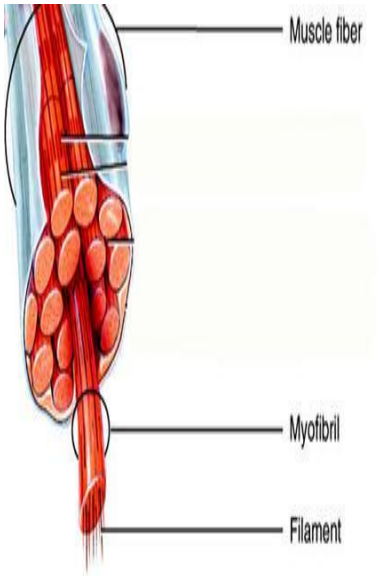
Muscle hypertrophy

- With training muscles hypertrophied 30- 60 % due to increased DIAMETER of the muscle fibers more than the number of fibers. "fibers=muscle cells"
- Exercise hypertrophy is due to increase in contractile protein (number of actin &myosin filaments in each muscle fiber).
- When number of contractile proteins increases sufficiently, myofibrils split within each muscle fiber 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.



- More than the number of muscle fibers :

المقصود أن الزيادة تكون في حجم العضلة نظراً إلى زيادة حجم الألياف العضلية, وهذه الزيادة في الحجم تفوق الزيادة في عدد الألياف العضلية.

- How ? increase in the myofibrils number (be careful it is myofibrils NOT muscle fibers)
- Contractile proteins = actin & myosin

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Types of muscle fibers

	Slow twitch fibers" Aerobic"	Fast-twitch fibers"Anaerobic"
Fibers Color	Red Fibers	White Fibers
Myoglobin Amount	HIGH	LOW
Fibers Characteristics	Small & Innervated with Small nerve fibers	Large & Innervated with Larger Motor Neurons
Sarcoplasmic Reticulum	Extensive sarcoplasmic reticulum for rapid release of calcium	
Mitochondria	Large Number, to support HIGH oxidative metabolism	Fewer number, cause oxidative metabolism is LESS important
Capillary Density	Higher capillarity	Lower Capillarity
Suited Activity	Prolonged endured activity Ex: Marathon runners	Forceful Rapid Contraction Ex: Sprinters
Glycolytic Enzymes	have a lot of glycolytic enzymes for rapid release of energy	
Duration of Use	minutes to Hours	Seconds to minute
Muscles used	Soleus muscle. "leg muscle"	Gastrocnemius muscle

Fast- twitch fibers are twice as large in diameter.

Video

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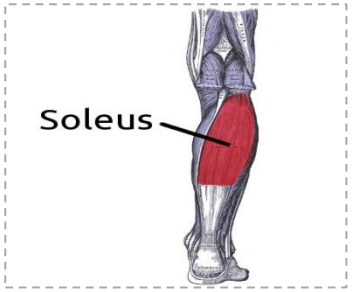
Types of muscle fibers

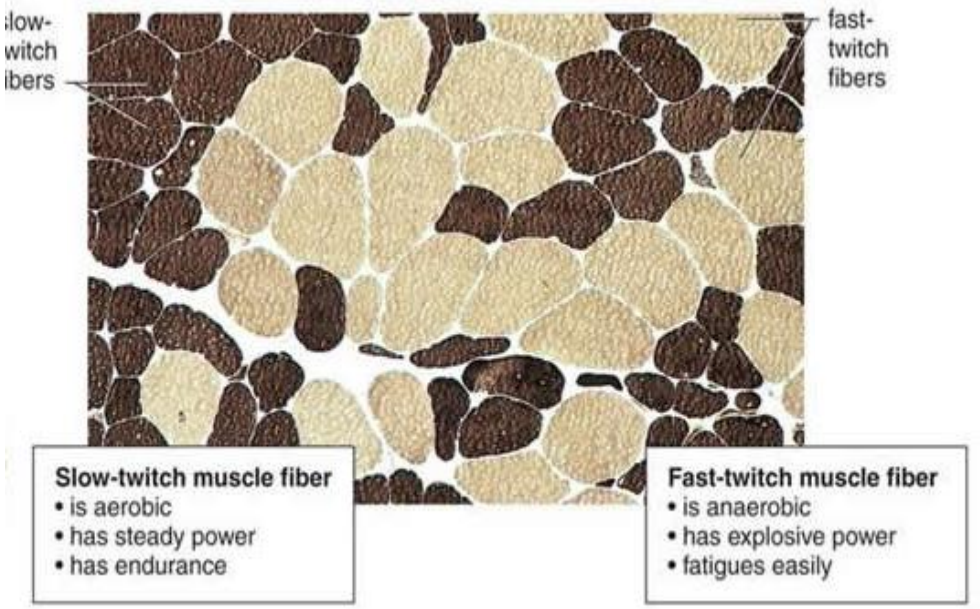
- In all human being, all muscles have varying percentages of **fast-twitch** and **slow-twitch** muscle fibers.

"كل عضلة في جسم الإنسان عندها النوعين من الألياف العضلية لكن نسبة النوعين تختلف من عضلة الى أخرى."



Soleus muscle
"Slow-twitch"

Gastrocnemius muscle
"Fast-twitch"



1-Anaerobic "fast-twitch" > fast & strong & for short time > white muscle fibers (deficient in myoglobin) > why without myoglobin? Because it's work without O2 > larger in size > lower capillarity& few mitochondria because no O2 present .
2-Aerobic "slow-twitch" > slow & prolonged > Red muscle fibers because it has myoglobin > Small > small nerve fibers > higher capillarity& large number of mitochondria because we need O2.

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Video

Respiration In Exercise

- In Exercise : Oxygen Consumption [VO2] and Pulmonary Ventilation [VE]
- VO2 at rest is about 250 ml/min, but at maximal effort (VO2 max) :

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

Pulmonary Ventilation = VE / Oxygen Consumption = VO2
كلهم يزيدون مع زيادة النشاط العضلي

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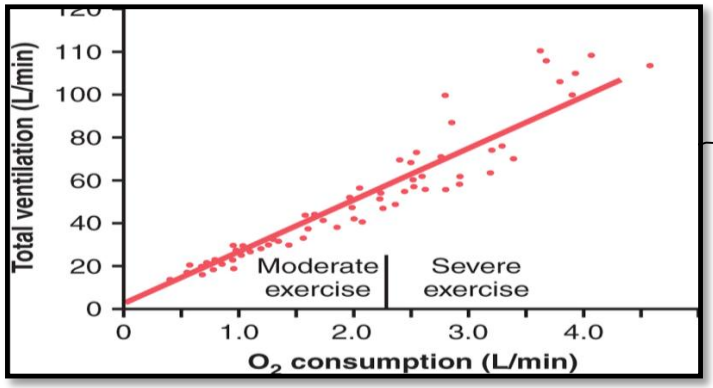
Respiration In Exercise

- The chart below shows the relation between oxygen consumption and total pulmonary ventilation at different levels of exercise :



- VO2 and VE increase about 20-fold between the resting state and maximal intensity (untrained).
- Maximal breathing capacity of an athlete can reach during maximal exercise 50% more than actual pulmonary ventilation.

- The schedule shows that pulmonary ventilation during maximal exercise doesn't occupy the whole volume of lung but the maximal breathing capacity is 50% more.

	L/min
Pulmonary ventilation at maximal exercise	100-110
Maximal breathing capacity	150-170

عند الشخص الغير رياضي > VO2 and VE increase about 20%
عند الأشخاص الرياضيين > VO2 and VE increase about 50%
لماذا ؟ نظراً لزيادة الـ chest capacity بالإضافة إلى زيادة pulmonary ventilation بالذات الـ
حجم العضلات مما يزيد من قوة التنفس.

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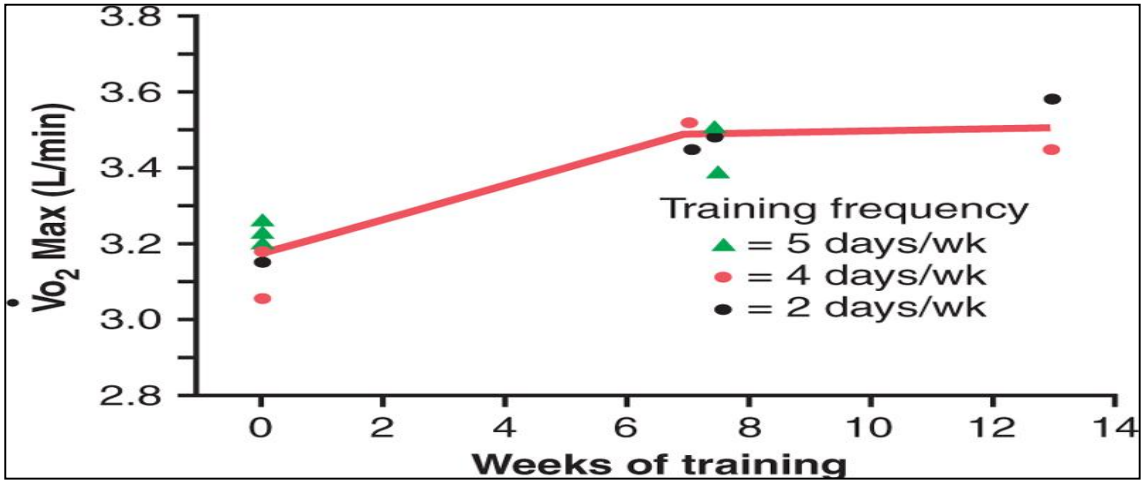
Respiration In Exercise

- Effect of Training on VO2 Max:

- Training will increase VO2 max by 10% but moreover other factors Genetic such as :

1. Chest size in relation to body size.
2. Stronger respiratory muscles.

- It is also likely that many years of training increase the marathoner's VO2 max.



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Oxygen diffusing capacity

- Oxygen diffusing capacity of athletes :

Is a measure of the rate at which oxygen can diffuse from the pulmonary alveoli into the blood.

- The following values are measured values for different diffusing capacities:

	ml/min
Nonathlete at rest	23
Nonathlete during maximal exercise	48
Speed skaters during maximal exercise	64
Swimmers during maximal exercise	71
Oarsman during maximal exercise	80

Oarsman : المجدّف

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Oxygen diffusing capacity

- O2 diffusion capacity increases 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).

O2 diffusion capacity with exercise 3 time faster than without it, why?
1- Increased of lung blood flow which leads to increase surface area for O2 to diffuse
2- When brain sends signals to the muscles to do hard exercise, muscle sends back signals to the brain to increase respiratory rate

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Cardiovascular System in Exercise

- **Cardiac output (CO) = stroke volume (SV) X heart rate (HR)**
- Muscle blood flow increases 25% folds during strenuous 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 **increases** oxygen consumption in turn dilates the muscle blood vessel thus **increasing** venous return and cardiac output (C.O).

- Cardiac output (CO) = كمية الدم التي يضخها القلب في الدقيقة الواحدة
- Cardiac output (CO) = stroke volume (SV) X heart rate (HR)
- SV = كمية الدم التي يضخها القلب في النبضة الواحدة
- HR= عدد نبضات القلب في الدقيقة الواحدة

كمية الدم التي يضخها القلب في الدقيقة الواحدة = كمية الدم التي يضخها القلب في النبضة الواحدة x عدد نبضات القلب في الدقيقة الواحدة

- When the cardiac output increased & O2 consumption increased > the diameter of blood vessel increased, so we don't get hypertension.
- الأشخاص الرياضيون غالباً غير معرضين للإصابة بارتفاع ضغط الدم لأن الأوعية الدموية تتسع لديهم [**Vasodilatation prevents hypertension**]
- When the cardiac output increased, it cause venous return

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Cardiovascular System in Exercise

Effect of Training on Heart Hypertrophy and on Cardiac Output:

- The heart-pumping effectiveness of each heartbeat is 40 to 50% greater in the highly trained athlete than in the untrained person. (Training increase C.O about 40 % greater than untrained persons).
- Heart chambers of marathoners enlarge about 40% in contrast to non trained.
- Heart size of marathoner larger than normal person

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

* It's very important to understand the difference between nonathletic and marathoner, the stroke volume and heart rate.
* Resting cardiac output is almost exactly the same as that in a normal person. This normal cardiac output is achieved by a large stroke volume at a reduced heart rate.

Cardiovascular System in Exercise

Typical cardiac outputs at several levels of exercise are as follows :

- 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 %
- Whereas the heart rate increases from 50 to 185 beats/min an increase of 270%
- Maximal cardiac output during exercise in a young untrained man : 23 L/min.
- Maximal cardiac output during exercise in average male marathoner : 30 L/min

athletes cardiac output increase depends on heart rate more than stroke volume, why?
Because stroke volume increase by 50%, on the other hand the heart rate increase by 270%

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Cardiovascular System in Exercise

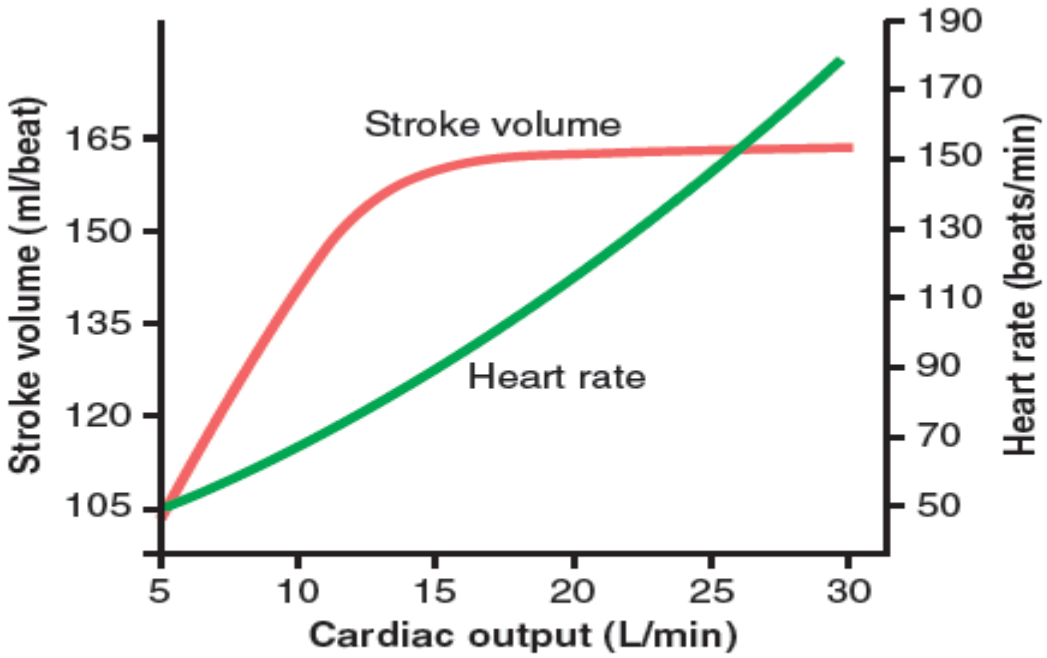


Figure 85-10. Approximate stroke volume output and heart rate at different levels of cardiac output in a marathon athlete.

*The heart rate increase a greater proportion of the increase in **cardiac output** than does the increase in **stroke volume**

This chart simply explain the relation between : heart rate, cardiac output and stroke volume

Body heat in exercise

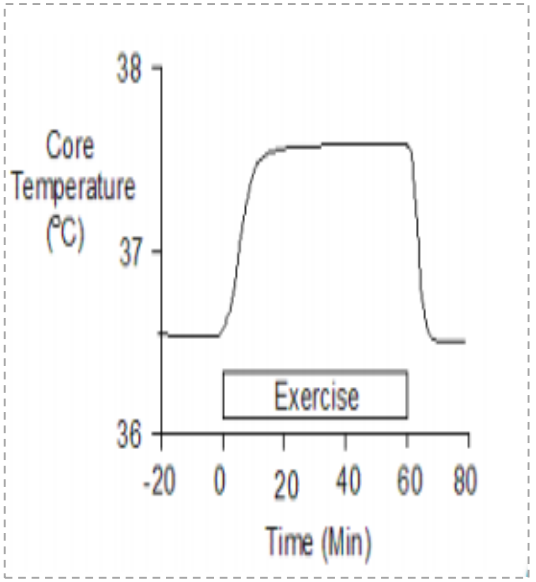
- Almost all the energy released by the body's metabolism of nutrient is converted into body heat.
- Working muscle uses only 20 - 25 % of energy released from metabolism.

Overcoming resistance to the movement of the muscles and joints.

Remainder converted into heat as result of:

Muscle contractile converted into heat.

Overcoming friction of the blood flowing through the blood vessels.



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Heatstroke

- If body temperature reaches 41 > damage of brain cells > highly fragile cells > زيادة الحرارة تسبب تلف في البروتينات وبما أنها خلايا ضعيفة إذاً تتلف البروتينات داخلها

During endurance training body temperature rises 37° to 40°C

In hot and humid conditions the body temperature can rise from 41° to 42°C

At this level, the elevated temperature becomes destructive to tissue cells, especially the brain cells

Heat stroke Symptoms

Body weakness → Exhaustion → Headache → Dizziness → Nausea → Sweating → Confusion → Uncontrolled Gait → Collapse → death

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Treatment of heatstroke

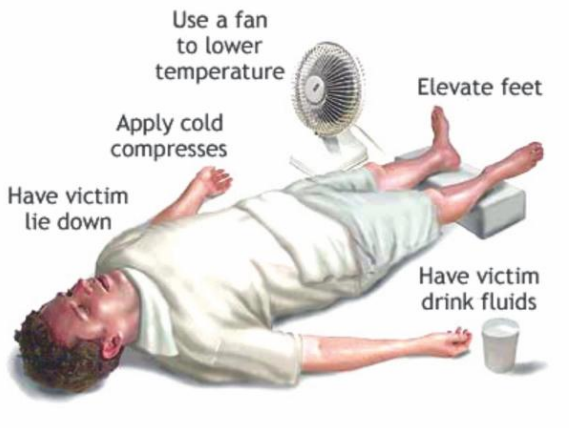
Remove all clothing

Maintain a spray of cool water on all surfaces of the body or continually sponge the body

The most practical way

Physicians and physiotherapists prefer total immersion of the body in water containing a mush of crushed ice if available

Blow air over the body with a fan



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The number	The situation of it
3-4 kg/cm2	size of muscle influence
* E.g. a cross-sectional area 150 cm2, cause maximal contractile strength of about 525 kilograms.	
30 %	Increased in strength after 10 weeks of training.
* E.g. muscle contractions sets against a 6 load X 3 days X one week greatly increase in muscle strength, without muscle fatigue.	
30-60 %	Increased in muscles hypertrophied due to increase diameter of the muscle fibers.
120 %	increase in mitochondrial enzymes in Hypertrophied muscle.
50 %	Increase in stored glycogen in Hypertrophied muscle.
75-100 %	Increase in stored triglyceride in Hypertrophied muscle.
45 %	Increase in oxidation rate in Hypertrophied muscle.
250 ml/min	VO2 at rest .
20-folds	The increasing of VO2 & VE between the resting state and maximal intensity "untrained".
50 %	The maximal breathing capacity of an athlete that can reach during maximal exercise is 50% more than actual pulmonary ventilation.
10 %	Vo2 max increased by training.
3-folds	Increasing in O2 diffusion capacity during exercise.
25 % folds	Increasing in muscle blood flow during strenuous exercise.
40 %	Training increase cardiac output about 40% greater than untrained person
5.5 L/min	The cardiac output in it's resting level.
30 L/min	Increasing in the cardiac output due to exercise.
105 ml	The stroke volume at the rest.
162 ml	Increasing in the stroke volume due to exercise.
* This mean increased by 50%.	
50 beats/min	The heart rate at rest.
185 beats/min	The heart rate due to exercise.
* This mean increased by 270%.	
20-25 %	The usage of energy released from metabolism, due to muscle work.
37°-40°C	Body temperature during endurance training.
41°-42°C	Increasing body temperature due to hot & humid conditions.

"This table includes the most Important numbers in this lecture"

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- فتون الصالح
- أفنان المالكي
- ربى السليمي
- منيرة العمري
- عائشة الصباغ
- شهد الدخيل
- نوف التويجري
- لينة الشهري
- روان الضويحي

- عمر العتيبي
- رواف الرواف
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- خليل الدريبي
- عبدالعزيز الحماد
- عبدالعزيز الغنايم
- عبدالمجيد العتيبي
- عبدالعزيز رضوان

Check your understanding!

QUIZ 1

QUIZ 2

مع جزيل الشكر والعرفان لـ : نوف التويجري – إلهام الزهراني – العنود العمير – نورة القحطاني – جواهر الحربي

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