Bioenergetic Systems

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Bioenergetic Systems

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– The Bioenergetic Systems.

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Introduction to Energy Systems

The food we eat is used to provide our body with energy.

The macronutrients, used as food fuels, are carbohydrates (CHO), fats and proteins. These food fuels enable the resynthesis of ATP.

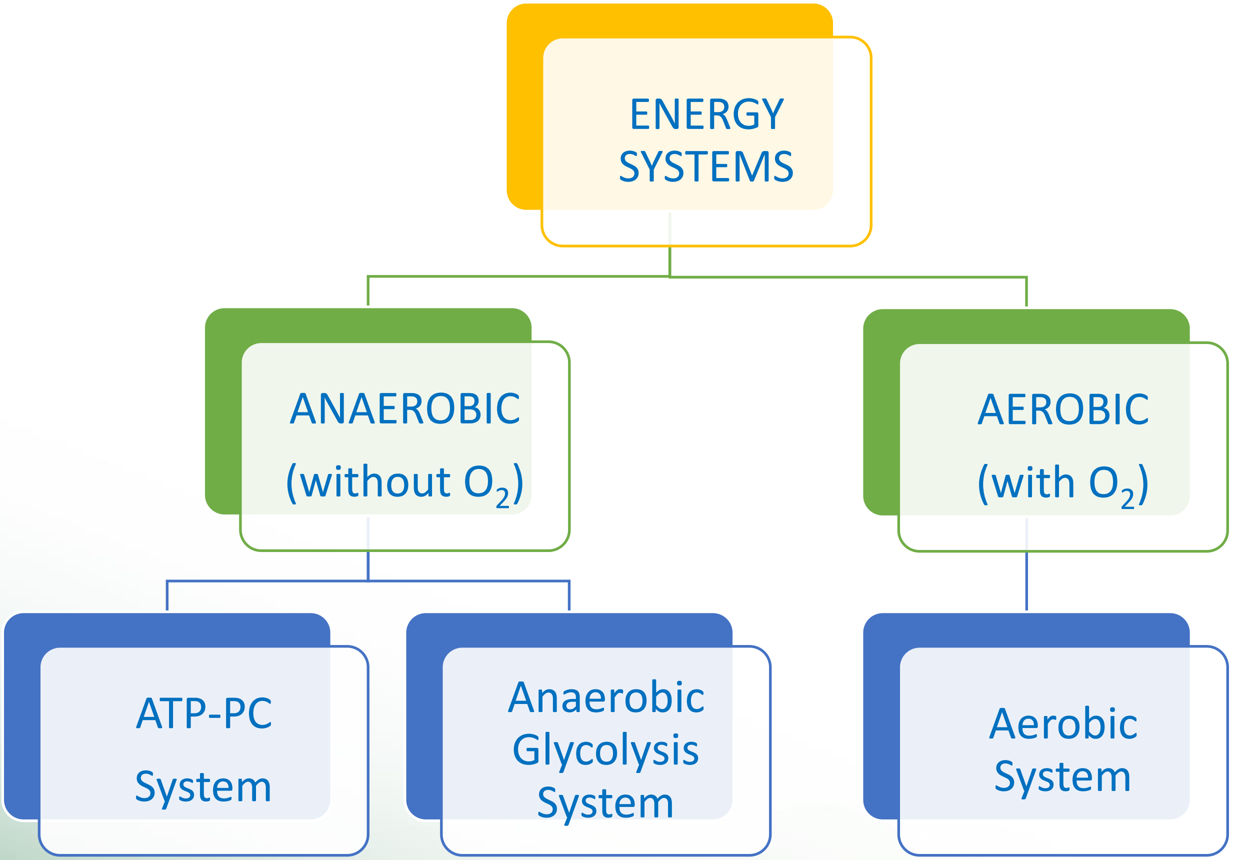
Every muscle contraction relies on the energy, which comes from the splitting or breakdown of adenosine tri phosphate (ATP).

The three energy systems all work together to resynthesise (recharge) the ATP to enable movement to continue, at various intensities and duration.

The three energy systems -

- ATP-PC system
- Anaerobic glycolysis system
- Aerobic system

The three energy systems



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Introduction to Energy Systems

ALL THREE ENERGY SYSTEMS WORK TOGETHER TO PROVIDE ENERGY, often referred to as the interplay of the energy systems

WHICH ENERGY SYSTEM IS USED DEPENDS ON –

- the **duration** of the exercise
- the **intensity** of the exercise
- whether **oxygen is present** or **not**
- the depletion of **chemical and food fuels** during exercise

Food Fuel..... What & Where is it stored?

THESE FOOD FUELS, ARE USED BY THE VARIOUS ENERGY SYSTEMS IN THE RESYNTHESIS OF ATP.

FOOD GROUP (macronutrient)	WHAT FOOD FUEL IS IT CONVERTED TO?	WHAT IS IT STORED AS? WHERE IS IT STORED?	WHEN IS IT MOSTLY USED?
CARBOHYDRATES (CHO) Sugars and starches - from cereal, breads & pasta, rice, fruit & vegetables	Glucose	GLYCOGEN - found in muscles and liver	Preferred source of fuel, especially during exercise
FATS &TRIGLYCERIDES Margarines, butter, oils, cheese, dairy products, fatty meat products	Free fatty acids (FFA)	ADIPOSE TISSUE - found at various body sites	Main source of fuel AT REST and during prolonged SUB MAXIMAL exercise
PROTEINS Lean meats, poultry, fish& seafood, eggs, lentils, grains and seeds, cheese	Amino Acids	MUSCLES – found at various body sites	Used mostly for growth & repair

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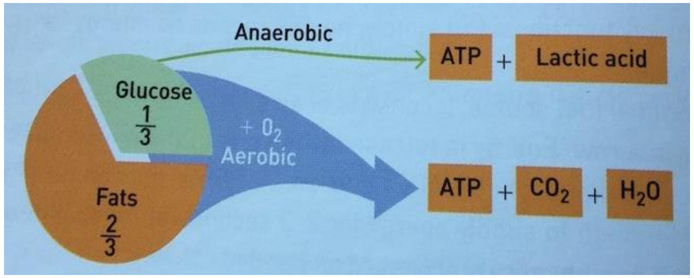
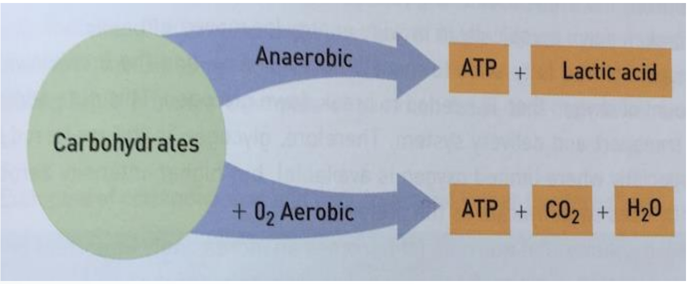
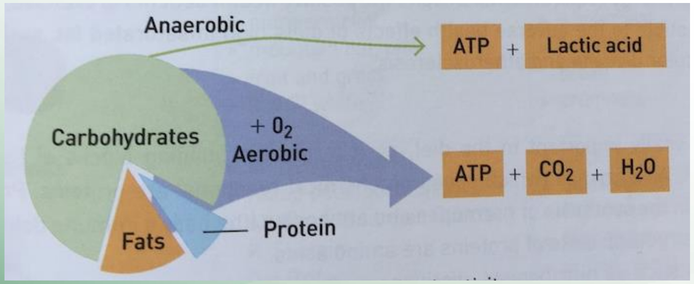
Contributions of food fuels



At REST – the body prefers the use of FATS over CHO (glucose)



At MAXIMAL activity – CHO is the only food fuel used at maximal activity. It is the body's preferred food fuel.

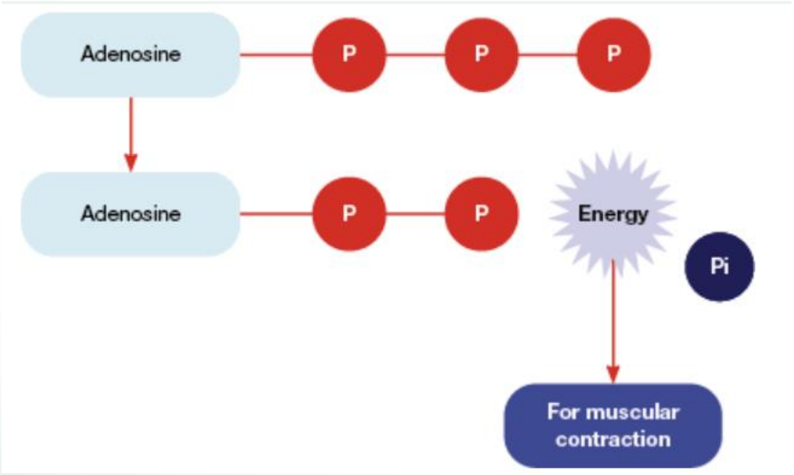


At SUBMAXIMAL activity – used increasingly during prolonged endurance events. Once glycogen stores start to deplete, more fats are called upon as a major fuel source

What is ATP and how is energy released?

ATP *ADENOSINE TRI-PHOSPHATE*

- ATP is made up of ADENOSINE and a chain of THREE PHOSPHATE groups (P), held together by high energy chemical bonds.
- The breakdown of ATP provides energy to power muscle contractions.
- This involves the breaking of the bond between the 2nd and 3rd phosphates to release a large amount of energy.



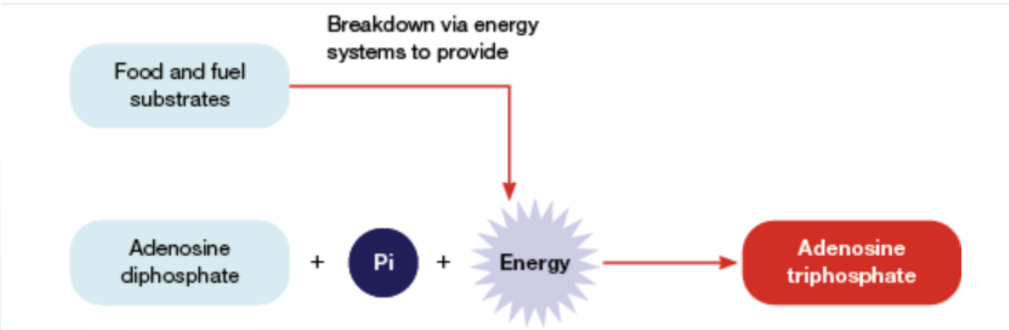
- When this occurs, ATP is broken down into adenosine di-phosphate (ADP) plus an inorganic phosphate (P_i) releasing the energy.

What is ATP and how is it resynthesised?

- Only a small amount of ATP is stored in the muscles, enough for a few maximal contractions, 2-3 secs.

- The body needs to replace ATP continually on an ongoing basis to enable movement to continue.

- The limited stores of ATP in the muscle is resynthesized from ADP and an inorganic phosphate (P_i) molecule. This is a process known as *phosphorylation.*



- It requires the addition of a P_i to the ADP (adenosne **di**-phosphate) to reform ATP (which is adenosine with three phosphates)

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What is ATP and how is it resynthesised? continued....

- As rapidly as ATP is broken down to supply energy for muscular contractions, it is continuously reformed from ADP and Pi.
- This requires energy, which is obtained from the breakdown PC, a substrate, also stored at the muscle site.
- Phosphocreatine (PC) is another chemical fuel source similar to ATP in that it contains a high energy phosphate bond. It can split into phosphate (P) and creatine (C).
- When a cell has excess energy, ATP is reformed with the rejoining of ADP by adding back the third phosphate P_{i}.
- This is assisted by the energy released from the breakdown of PC stored in the muscles.

Terminology & Definitions

AEROBIC METABOLISM

- when ATP is synthesized in ***the presence*** of oxygen (also referred to as oxidative *phosphorylation)*

ANAEROBIC METABOLISM

- when ATP is synthesized ***without*** the presence of oxygen

GLYCOLYSIS

- the process of breaking down glycogen

AEROBIC GLYCOLYSIS - the creation of ATP in the presence of oxygen

- the presence of sufficient oxygen allows pyruvic acid to enter the mitochondria and undergo this process (aerobic glycolysis) to produce more ATP

FUEL DEPLETION

- the depletion of energy fuels or substrates that serve to power muscular contractions,

Terminology & Definitions

ACTIVE RECOVERY

- low activity completed at the end of a workout usually (50-70% MHR) to encourage body to regain resting physiological state

EPOC (excess post-exercise oxygen consumption)

- the amount of O_2 consumed during the recovery period after the cessation of an exercise that is over and above the amount usually required at rest

METABOLIC BY-PRODUCTS

- are substances produced as a result of chemical reactions within the body associate with the production of energy for ATP resynthesis
  - ✓ lactic acid,
  - ✓ hydrogen ions (H+),
  - ✓ inorganic phosphate Pi
  - ✓ ADP adenosine diphosphate

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A summary….
Characteristics of the three energy systems…..

ATP – PC ENERGY SYSTEM

- produces energy by breaking down PC to resynthesise ATP (Adenosine Tri Phosphate)
- does not need the presence of oxygen – IT IS ANAEROBIC
- rapidly available – used in first 10 sec
- exhausted rapidly (low yield) – finite supply of PC in muscles

ANAEROBIC GLYCOLYSIS ENERGY SYSTEM

- produces energy by the incomplete breakdown of glycogen
- does not need the presence of oxygen – IT IS ANAEROBIC
- produces energy slower than ATP-PC system
- produces lactic acid – causing fatigue
- peak power reached between 5 – 15 seconds, can be dominate energy system 10-45sec

AEROBIC ENERGY SYSTEM

- produces energy in the presence of oxygen – IT IS AEROBIC
- energy production is limited by oxygen capacity ($V0_2$max)
- produces less power than other systems
- does not create any fatiguing by products
- Preferentially breaks down CHO rather than fats to supply energy for exercise

The ATP-PC Energy System

This provides the most rapidly available source of energy available to for muscle contraction and enables resynthesis ATP.

It only relies on ATP and PC already stored in the muscles, so is the least complicated system. Chemical reactions only are required at the muscle site.

This energy system has the fast rate of energy production, yet the smallest yield.

It is considered an ANAEOBIC energy system, as it does not rely on the presence of O_2.

As quickly as the ATP is being broken down for muscular contraction, it is continually being resynthesized from ADP and Pi, by the use of the energy stored in PC. (**p**hospho**c**reatine)

The ATP-PC Energy System

HOWEVER……The stores of both ATP and PC in the muscles is finite.

As ATP stores only last for approx. 2-3 secs of maximal intensity activity, the role of PC in ATP's resynthesis is important.

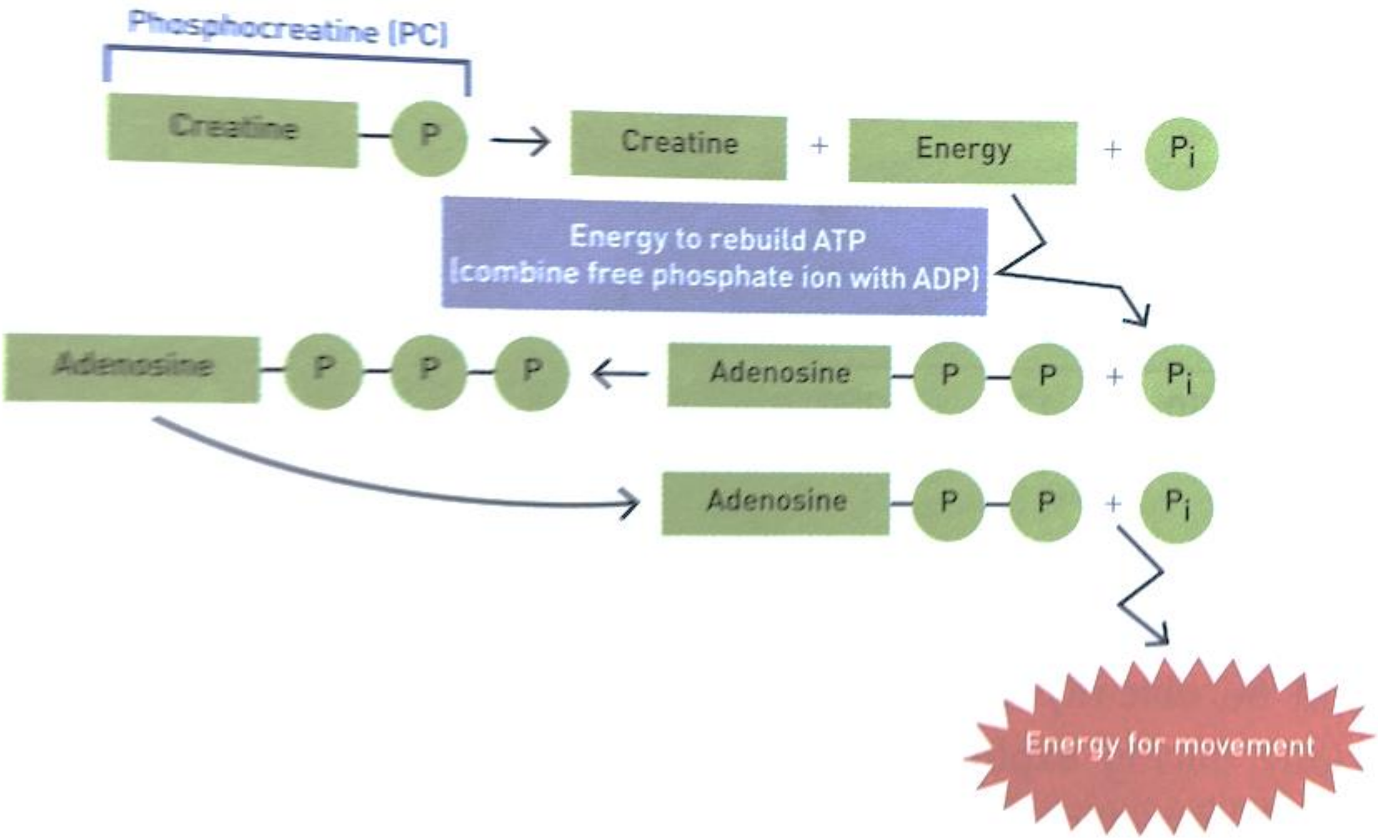
PC breaks it's bond to split into phosphate P_i and creatine.

The breaking of bond creates energy to enable the resynthesis of ATP (eg. adding a phosphate P_i back onto ADP to make ATP)

ATP resynthesis will continue until all PC stores are utilized, lasting approximately for 6-8 sec of high intensity exercise.

Combined, the ATP-PC system can enable maximal exercise for approximately 8-10 sec.

The ATP-PC Energy System



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The ATP-PC Energy System

Without ATP resynthesis, the activity's intensity cannot be maintained, resulting in fatigue. (eg. a loss of force being able to be generated)

It is the finite stores of PC that is the limiting factor of the ATP PC system to enable high intensity activity to continue indefinitely.

PC stores can be replenished, through passive recovery, within approximately three minutes of the exercise finishing.

At the completion of exercise, with a passive recovery – most of ATP and PC intramuscular stores are replenished in approximately 3 mins (see table)

If the activity is to continue the body must rely predominantly on another energy system to provide energy for ATP resynthesis.

This energy system provides most of the power, and energy required during the starting sequence at start of the dragon boat race, however is limited and depletes after about 10 seconds.

Passive recovery – Restoration rates of ATP & CP

Time frame	Percentage of ATP & CP restored
Within 20 seconds	50%
Within 30 seconds	70%
Within 40 seconds	75%
Within 60 seconds (1 minute)	87%
Within 3 minutes	Approximately 100%

Note - Passive recovery = resting, minimal activity

Anaerobic Glycolysis Energy System

ANAEROBIC GLYCOLYSIS refers to the incomplete breakdown of glucose to provide energy for ATP resynthesis, when oxygen is NOT AVAILABLE.

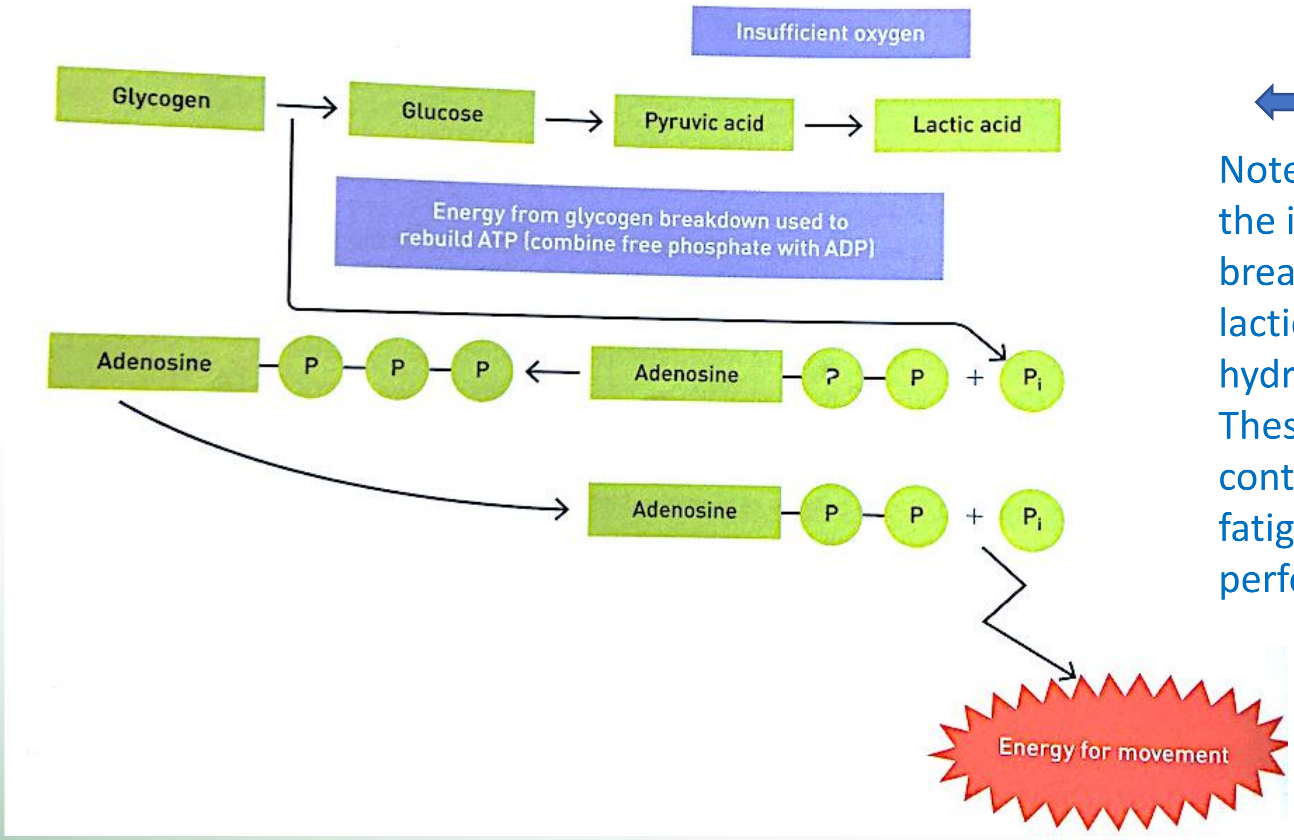
This incomplete breakdown produces **pyruvic acid,** which is then converted into **lactic acid**.

A byproduct of this process is the accumulation of **hydrogen ions (H+)**

This causes the pH of the muscle to fall (become more acidic), which inhibits glycolysis, due to the decrease in enzyme activity, and the interference with the muscle contractile mechanisms, causing fatigue.

The build up of H+ ions cause the inability of the muscles to contract maximally after a short period of time.

Anaerobic Glycolysis Energy System



Note the by-products of the incomplete breakdown of glucose - lactic acid, lactate & hydrogen ions (H+) These can inhibit muscle contraction and cause fatigue and a decrease in performance.

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The Anaerobic Energy system & Lactic Acid

The by-product, lactic acid creates an acidic environment in the muscles and blood.

The acidity, causes a build up of hydrogen ions (H+) which inhibits the muscle contractions.

The build-up of lactic acid causes intense fatigue that is characterised by a burning and heavy feeling in the working muscles.

The Anaerobic Energy system supplies most of the energy between the 10 to the 45 second mark in a dragon boat race. As a result lactate has accumulated during the race.

Light (40% of max) aerobic activity can speed the clearance of lactic acid. As lactic acid clears, it is converted back to glycogen. Hence, the importance of a cool down after anaerobic activity is highlighted.

To clear a large amount of lactic acid, it takes approximately
30 minutes of rest.

Anaerobic Glycolysis Energy System

HOWEVER, hydrogen ions combine with pyruvate to form lactate, which is converted to glycogen and made available for further energy.

About 80% of this lactate acid is diffused from the skeletal muscles and is transported to the liver to be converted back to glucose or glycogen.

When the rate of accumulation of lactate/lactic acid in the blood is greater than than the rate at which it can be oxidized, lactate in the blood accumulates.

When LIP (Lactate Inflection Point) is exceeded, fatigue and a drop in performance occurs.

By exercising under LIP, the build up of fatigue/limiting by-products is reduced.

Activities of maximal intensity that are longer than 10 seconds use this energy system.

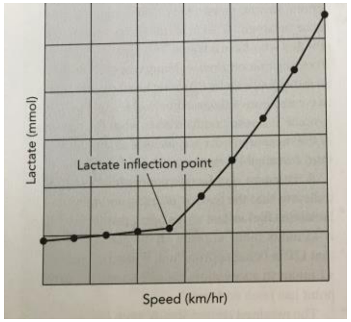
LACTATE INFLECTION POINT

Lactic acid is produced whether energy is created with or without O_2 being present.

At low intensities, the amount of lactate produced is able to be oxidized (removed) at the same rate of production, so there is not an increase in it's concentration.

LIP is considered the point, when the exercise intensity produces more lactate than can be removed for the blood, typically around 3-4 mmol/L.

When LIP is exceeded, and blood lactate levels increase rapidly, fatigue then follows.



The higher the exercise intensity is above LIP, the quicker the fatigue will occur.

When lactate accumulates in the muscles, H+ (hydrogen ions) accumulate, which interfere with glycolytic enzymes and the contractile mechanisms in the muscles.

LACTATE INFLECTION POINT

Many endurance athletes train to be able to work at, or just below, their LIP. This is the maximum speed they can perform at, without the increase in lactate, and hence the accumulating hydrogen ions (H+) that lead to fatigue.

The maximal lactate steady state (MLSS) is when exercise intensities are predominately aerobic and the. Lactate level remains constant.

LIP is often referred to as OBLA - Onset of Blood Lactate Accumulation, and is often discussed together in relation with Anaerobic Threshold and it's training.

Anaerobic training, such as intermediate-interval training, results in the body producing large amounts of lactate.

The more frequently this occurs during training with the session continuing above LIP, the more likely the body is to adapt to producing large amounts of lactate.

By improving the body's clearance and buffering capacity, the muscles learn to tolerate higher lactate concentrations.

The Aerobic Energy System

THE AEROBIC ENERGY SYSTEM

- is the slowest energy system as it involves a complex nature of chemical reactions.
- is able to resynthesis ATP using a variety of food fuels, through the break down of -
  - ✓ glycogen (preferred during exercise),
  - ✓ fats (preferred at rest) or
  - ✓ amino acids (as a last measure)

This energy system is capable of providing the greatest yield of ATP, (30-50 more times, than the anaerobic energy systems combined) yet does so at the slowest rate.

The aerobic system is also activated at the start of exercise, however peak power is not reached around the 1-2 minute mark.

AEROBIC ENERGY PRODUCTION FROM CARBOHYDRATES

Aerobic energy production from carbohydrates includes three processes

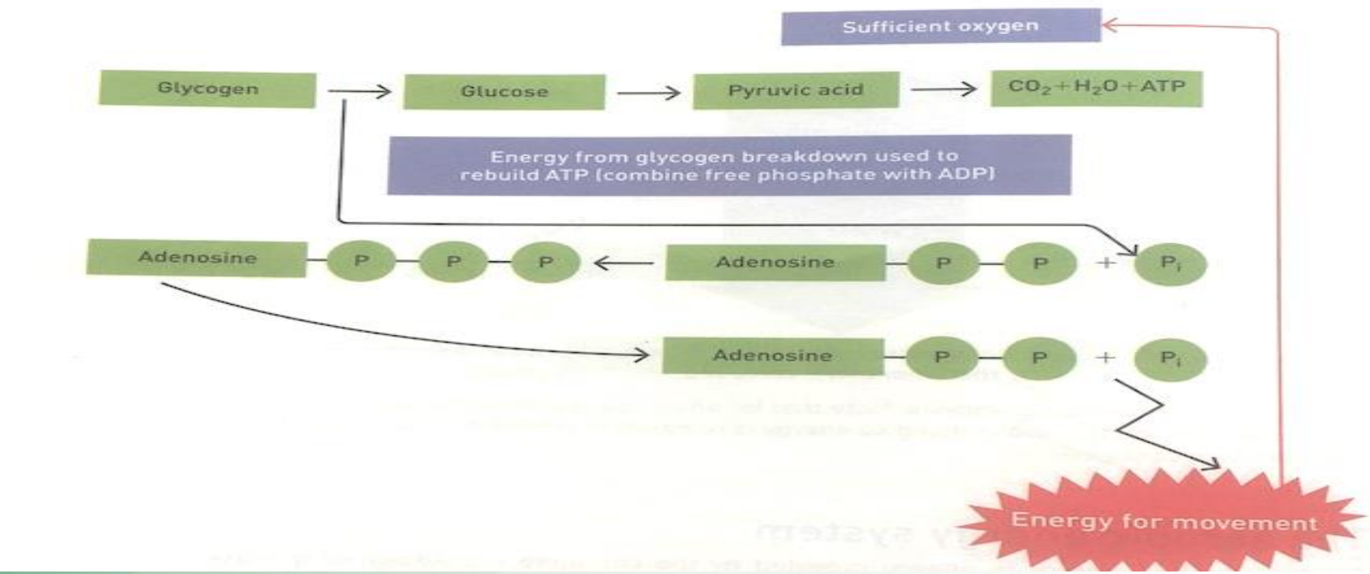
- ✓ aerobic glycolysis
- ✓ the Krebs cycle
- ✓ the electron transport chain

The Aerobic Energy System

AEROBIC ENERGY PRODUCTION FROM CARBOHYDRATES

AEROBIC GLYCOLYSIS refers to the complete breakdown of glucose to provide energy for ATP resynthesize, when sufficient oxygen IS AVAILABLE.

With sufficient oxygen, pyruvic acid is converted to acetyl co enzyme A
This is then channeled into the Krebs Cycle. (rather than converted into lactic acid – as in anaerobic glycolysis)



The Aerobic Energy System

AEROBIC ENERGY PRODUCTION FROM CARBOHYDRATES

THE KREBS CYCLE

- Is a series of complex chemical reactions that continues the oxidization of glucose that was started during aerobic glycolysis
- Involves a series of enzymatic reactions involving the oxidative metabolism of coenzyme A enters the Kreb cycle and is broken down into carbon dioxide (CO2) and hydrogen, which releases energy for the resynthesize of ATP.
- The hydrogen ions produced in the Krebs cycle are then transported to the Electron transport chain.

THE ELECTRON TRANSPORT CHAIN

- Is the third and final stage in aerobic metabolism.
- Hydrogen ions, H+ combines with oxygen to form water (H_2O) This process provides in even more energy for ATP resynthesis being produced.
- The by products of this process is CO_2 and water (H_2O) both of which can be easily removed from the body

Aerobic Energy System

THE KREBS CYCLE……

- Both the Krebs cycle and the electron chain stage occurs in the mitochondria.

- The greater the number of mitochondria within the muscle cells the greater the capacity for energy production.

  (*MITOCHONDRIA – are the cell structures that are the "powerhouse" of the cell, converting nutrients into ATP*)

AEROBIC ENERGY PRODUCTION FROM FATS

The aerobic energy system can metabolise FATS to produce energy for ATP resynthesis

AEROBIC LIPOLYSIS

- This is the breakdown of fats (triglycerides) into glycerol and free fatty acids.
- These are then further broken down to acetyl coenzymes (via beta oxidation)
- Once in the Krebs Cycle, fat metabolism follows the same path as for CHO.

Aerobic Energy System

AEROBIC ENERGY PRODUCTION FROM PROTEINS

- Is thought to make only make a minimal contribution to energy production (5-10%)

- Amino acids, the building blocks of protein, can be either converted to glucose or other intermediates via the Kreb Cycle.

- In very prolonged exercise, eg. ultra marathons, perhaps as much as 15 % of total energy can come via protein. It is not desirable as it involves the breakdown of proteins in the body.

The Aerobic Energy System

The aerobic system is used for base metabolism, creating the energy used by the body at rest and when exercising at sub maximal efforts longer than 45 seconds. This system dominates from the 45 second mark in a dragon boat race.

It creates less peak power than the anaerobic systems, but is more sustainable and creates less fatigue. (by-products are CO_2, heat and H_2O)

The aerobic system fatigues when it runs out of fuel stores. Approximately 90 minutes of aerobic glycolysis is possible before depleting the glycogen in the muscle stores. However, the amount of stored glycogen is trainable.

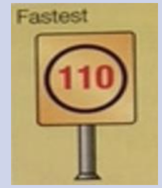
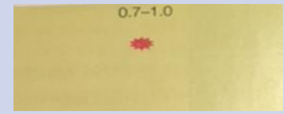
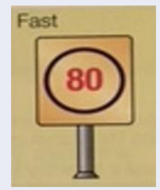
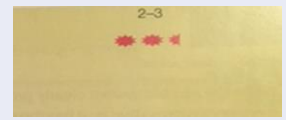
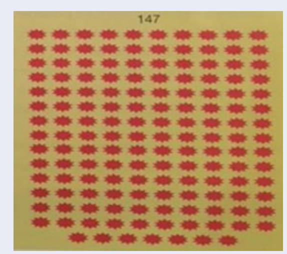
After glycogen depletion, fats become the main fuel for the aerobic system, through aerobic lipolysis.

The ATP yield is higher, although it cannot maintain rate of ATP production possible during aerobic glycolysis, so the intensity of the exercise may need to drop. aerobic system has the ability to clear any lactic acid, provided LIP has not been reached. (refer to slide on LIP)

A summary - Energy Systems

Energy System	Duration (sec.)	Classification	Energy Source
ATP + CP	1-4	Anaerobic	Muscle ATP Stores
	4-20		Muscle ATP & CP Stores
Anaerobic Lactic Acid	20-40	Anaerobic	Muscle ATP, CP, & Glycogen Stores
	40-120		Muscle Glycogen & Lactic Acid
Aerobic	120-2400	Aerobic	
	2400-6000		Muscle Glycogen & Fatty Acids

Each red dot represents the yield of ATP

ENERGY SYSTEM		FUEL USED	RATE OF ATP PRODUCTION	TOTAL AMOUNT OF ATP (YIELD)
ATP-PC system		Phosphocreatine (PC)		
Anaerobic glycolysis		Glucose		
Aerobic system	Aerobic glycolysis	Glucose		
	Aerobic lipolysis	Fatty Acids		

0.7-1.0 ATP for each glucose molecule

2-3 ATP for each glucose molecule

36-38 ATP for each glucose molecule

147 ATP for each glucose molecule

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RELATIVE CONTRIBUTIONS OF BOTH ENERGY SYSTEMS TO MAXIMAL EXERCISE

Duration of maximal exercise (seconds)	Anaerobic ES contribution (%)	Aerobic ES contribution (%)
0 - 15	88	12
0 - 30	73	27
0 - 45	63	37
0 – 60 (1 min)	55	45
0 - 90	44	56
0 – 120 (2 min)	37	63
0 – 180 (3 min)	27	73
0 – 240 (4 min)	21	79

200m

500m

1000m

(Data from study of both trained and untrained individuals during run, swim, bench or cycle ergometry exercise – Gastin 2001.)

The interplay of the energy systems

REST TO EXERCISE TRANSITIONS

- all energy systems are contributing towards ATP production simultaneously throughout the exercise bout.
- the proportional contribution of ATP from each system to the metabolic demand will change depending on exercise intensity and duration.
- There is a gradual transition from one energy system to another as duration and intensity changes during exercise.

FROM REST TO MAXIMAL INTENSITY EXERCISE (0 to 6 seconds)

- The ATP-PC system is the only system able to meet demands of the explosive, high intensity exercise.
- All energy systems will produce ATP at a slower rate, with proportional contribution being minimal

The interplay of the energy systems

FROM REST TO HIGH INTENSITY EXERCISE (30 to 45 seconds)

After the first 6 seconds, there is a shift to anaerobic glycolysis, (from the ATP-PC system) due to the depletion of PC stores in the muscle.

Towards the end of the exercise bout, the aerobic energy system contribution to ATP production will be significant.

For the exercise to continue the intensity may need to decrease, in order to avoid the build up of fatiguing by products (lactate).

FROM REST TO LOW/MODERATE INTENSITY EXERCISE

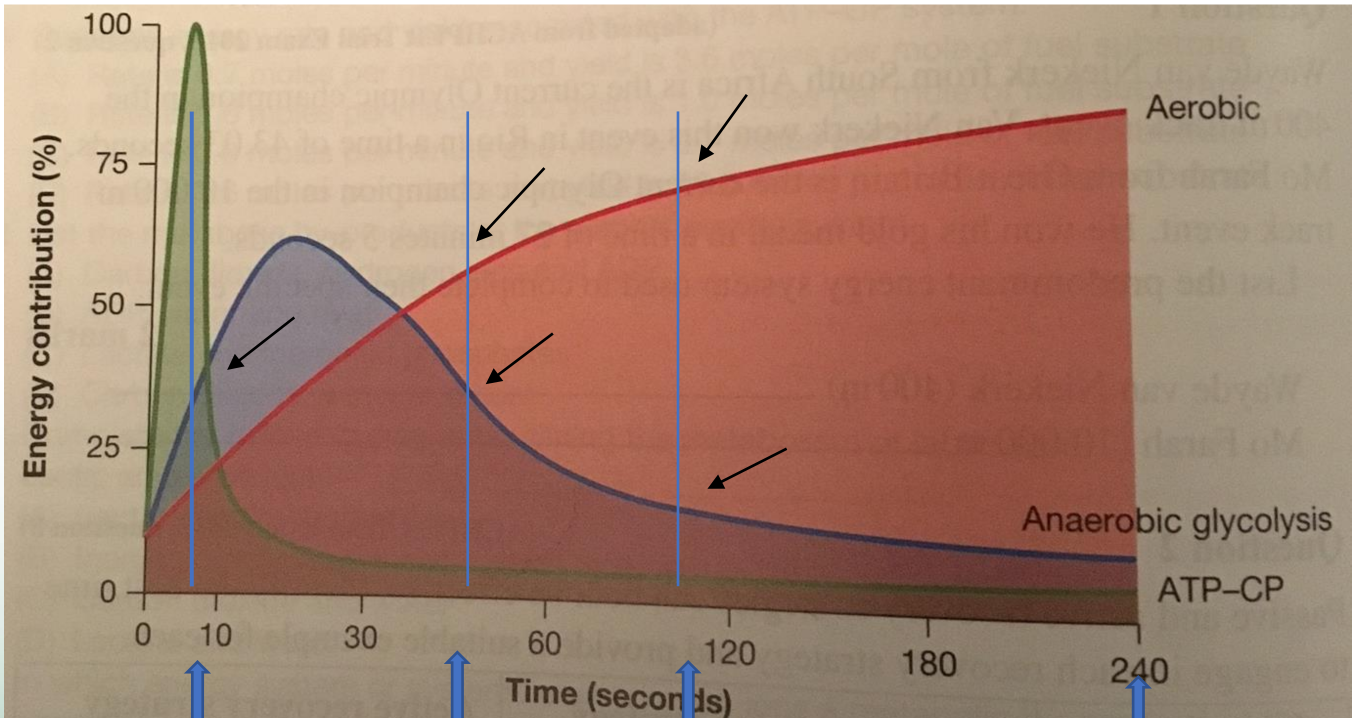
The respiratory and circulatory systems are unable to meet the immediate increased oxygen demands of the body in in moving from a resting state.

The anaerobic energy systems supplements the production of ATP (eg. supplies energy at the very start (without O_2) until the body is able to increase O2 delivery to the muscles to meet the O_2 demands of the activity.

Which energy system is being used?

Relative contribution of energy systems during exercise

(energy contribution. Vs time)



First 10 strokes…

200m

500m

1000m

Arrows are pointing out the relative contribution of each energy system at the end of start, 200m & 500m race distance

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from Jacaranda – Live It Up Bk2, p194

ENERGY SYSTEM CONTRIBUTION IN RACING

Dragon Boats have a lot of inertia and require much power to accelerate to top speed.

The ATP-PC system fuels the start and ceases to produce most of the power at the 10-15 second mark by which time the boat is up to top speed or close to it. Its contribution is limited due to limited supply of PC.

At this point, anaerobic glycolysis becomes the dominant source of energy, still without O_2, however also producing fatiguing by-products.

As the aerobic system becomes more able to supply O_2 to the muscles, it's contribution increases. At approximately the 45 second mark, the aerobic system begins to produce most of the energy, however, the anaerobic glycolysis system does not switch off completely, but continues to contribute some energy.

While contributing, it is also producing lactic acid, and with exercise at a high intensity, the rate of production may exceed the rate of clearance (eg.LIP) causing fatigue. From approximately the 45 second mark the aerobic energy system is the dominate energy supplier, and depending on the intensity of the exercise, (below LIP) a steady state can reached.

What energy system is used during Dragon Boat Races?

200M DRAGON BOAT RACE

- The race typically lasts for approximately 45-55 sec.
- The start of the race, from resting, requires the explosiveness of the ATP-PC System.
- It can be seen from the graph, that during the start of the race, the predominate energy system supplying energy is the Anaerobic ES, with both ATP-PC initially being used, followed by Anaerobic Glycolysis (both without the use of oxygen).
- As the race continues, although being utilised from the start in small proportion, there is an increasing reliance on the Aerobic Energy System.
- From the table, it can be seen the relative contributions for a 200m race are approximately - 63% Anaerobic and 37% Aerobic.
- The 63% Anaerobic contribution is made up of the initial ATP-PC System, followed by the Anaerobic Glycolysis System.

What energy system is used during Dragon Boat Races?

500M DRAGON BOAT RACE

- The race typically lasts around 2 minutes.
- All energy systems play a significant part and both the ATP-PC and the anaerobic glycolysis enables the start of the race to be explosive.
- The aerobic system, from about the 45sec mark will become the dominate energy supplier and plays the largest role overall.
- A well-developed aerobic system will engage faster, will result in less lactic acid produced and is removed quicker, minimising the decrease in intensity and performance.
- It is suggested that the 500m event is approximately 15% ATP-PC, 25% lactic and 60% aerobic.

What energy system is used during Dragon Boat Races?

1000M DRAGON BOAT RACE

- The race typically lasts over four minutes.
- Due to the duration of the event it relies predominately on aerobic energy.
- The race distance depends on approximately 10% ATP-PC, 15% lactic and 75% aerobic. (based on studies based on gas analysis & testing in similar sports such as canoeing and kayaking)

  (also refer back to slide with graph and table on relative contributions of energy systems.)

- It can be noted that for the requirements of the 500m and 1000m races are fairly similar, both requiring extensive development of the aerobic system where the 200m event does not.

PHYSIOLOGICAL ADAPTATIONS TO TRAINING

What physiological changes occur within the body to improve the capacity of the aerobic and anaerobic energy systems?

ACUTE RESPONSES TO EXERCISE are the body's immediate, short term responses, that last only for the duration of the training or exercise session, and for a short time period (recovery) afterwards.

CHRONIC ADAPTATIONS TO EXERCISE are the body's long term responses of the that develop over a period of time, when training is repeated regularly.

These can involve the cardiovascular, respiratory and muscular systems, all affecting the efficiency of the body to produce energy.

The main purpose of training is to improve the athletes physiological capacity to meet the demands of the competition.

Careful planning and the manipulation of training variables can enhance the athlete's chronic adaptations described in the next slides.

PHYSIOLOGICAL ADAPTATIONS TO TRAINING…..

Anaerobic - RESPIRATORY ADAPTATIONS

HEART

- **increase ventricle thickness**
  - heart wall is thicker, enabling a more forceful contraction of blood out of the heart during systole

BLOOD VESSELS

- **increased vascularisation (not as much as with O2 training)**
  - as a result of increase in muscle size

BLOOD

- **decrease blood pressure (rest & sub max)**

Anaerobic - MUSCULAR ADAPTATIONS

- **increase in anaerobic enzyme concentration**, (myosin ATPase, glycolytic enzymes
  - speeds up anaerobic production of ATP, and rapid contraction
- **increase in FT (fast twitch) fibre size**
  - allows greater contractile force to be generated
  - allows greater storage of ATP and PC and extends the use of the ATP-PC system and less reliance on anerobic glycolysis
  - allows for greater glycogen stores in the muscles

PHYSIOLOGICAL ADAPTATIONS TO TRAINING…

Anaerobic - MUSCULAR ADAPTATIONS

- **increase in the recruitment of FT fibre**
  - increasing the capacity to produce force.
- **increased muscle buffering capacity**
  - improved tolerance to & the ability to neutralise excess lactic acid
  - improved work under fatiguing elements
- **improved neural transmission**
  - nervous system and muscular system work better to allow for efficient movements and greater force/contractile summation
  - increase in speed of contractions
  - Increase force of contraction
- **increase size of connective tissues and tendons**
  - provides greater attachment to muscles and assists in force production
- **decrease in lactic acid production (sub max exercise)**
- **decrease in recovery times**
  - body becomes better at resynthesise used fuels
- **improved control of calcium within the muscle fibre**
  - aids muscle contraction.

PHYSIOLOGICAL ADAPTATIONS TO TRAINING…

Aerobic - CARDIOVASCULAR ADAPTATIONS

THE HEART

- **increase in ventricle size increase** – enables an increase in SV & Q, and enables more blood, O_2 and fuels to be efficiently transported to the working muscles
- **increased stroke volume (SV)**
- **increase in Cardiac Output (Q)-** increases blood supply and cardiac output.
- **decrease in heart rates** – rest, sub maximal, steady state, recovery rates

BLOOD VESSELS

- **increase capillary density to heart muscle**
  - more blood pumped to heart and actual muscles lowering potential anaerobic by products causing fatigue.
- **increased blood flow (away from organs to the working muscles)**
- **increased capillary density at muscles (mainly ST fibres)**
- **increase in HDL & decrease in LDL** – assists in the removal of plaque, resulting in less resistance in blood vessels

PHYSIOLOGICAL ADAPTATIONS TO TRAINING…

Aerobic CARDIOVASCULAR ADAPTATIONS

BLOOD

- **increase in blood volume**
  - increases the amount of O2 transported to the working muscles
  - assists in the removal of by-products
- **increase in red blood cells (RBC)**
  - increases the ability to transport O_2 to, and CO_2 from the working muscles.
- **Increase in plasma levels**
  – slows fatigue caused by dehydration & elevated body temperature
- **increase in haemoglobin** – assist in greater O_2 transportation to the muscles
- **increase in myoglobin** – increases the rate of O_2 transfer to mitochondria
- **increase in OBLA**
  – enables more O_2 to meet the demands of the intensity of exercise and delays LIP
- **decrease in blood pressure (rest & sub max)** – cardio protective effect

PHYSIOLOGICAL ADAPTATIONS TO TRAINING…

Aerobic RESPIRATORY ADAPTATIONS

- **increase in lung/vital capacity**
  – more O2 can be taken in to be transported around the body
- **increase in aerobic capacity (VO_2max)**
  – allows use of aerobic system for greater part of exercise, assists PC restoration
- **increase in tidal volum**e
- **increase alveolar-capillary surface area**
  – allows for greater diffusion and amount of gaseous exchange in the lungs
- **increase pulmonary diffusion**
- **increase ventilation (max intensity)**
- **decrease oxygen cost to ventilatory muscles (intercostals & diaphragm)**
  - more available O2 available for use by the muscles
- **decreased ventilation (rest** & sub max)

PHYSIOLOGICAL ADAPTATIONS TO TRAINING…

Aerobic MUSCULAR ADAPTATIONS (SLOW TWITCH FIBRES)

- **increase mitochondria (number, size and surface area)**
  - allows for greater aerobic ATP release (oxidative enzymes also do this)
- **increase myoglobin stores**
- **increase oxidative enzymes**
  - speeds up aerobic production of ATP and the muscles use of O_2.
- **increase glycogen & triglyceride stores**
  - enables muscles to work for longer before fatigue
- **increase in slow twitch fibre size – assist in force production & fuel storage**
- **increase ability for glycogen sparing**
  - the training of muscles to use fats rather than glycogen, allowing for greater use later in the exercise bout

PHYSIOLOGICAL ADAPTATIONS TO TRAINING…

Aerobic MUSCULAR ADAPTATIONS (SLOW TWITCH FIBRES)

- **increase ability for glycogen sparing**
  - the training of muscles to use fats rather than glycogen, allowing for greater use later in the exercise bout
- **increase in glycogen synthase** - enzyme to assist in the storage of glycogen from glucose
- **increase muscle capillary supply & density**
  - allowing greater O_2 supply and CO_2 removal.
- **increase in a-vO_2 difference (arterial-venous oxygen difference)**
  - more O_2 can be extracted by the working muscles
  - enhances supply of O_2 and by product removal

MUSCULAR ADAPTATIONS (FAST TWITCH TYPE IIA FIBRES)

- as above but to a lesser extent
  - increasing the total aerobic power available

VO_2 Maximum. (Maximum Oxygen Uptake)

- is a key measure of aerobic power (also known as aerobic capacity, cardiovascular endurance)
- is the maximum amount of oxygen that can be used by the muscles to produce work, measured in millilitres (mL) per kilogram of body weight per minute (ml/kg/min)
- is defined as the point at which oxygen consumption ceases to rise despite an increase in exercise intensity
- is the best way of measuring efficiency of your circulatory, respiratory and muscular systems under exercise conditions

Some tests commonly used to measure VO_2 max

- ✓ treadmill tests (direct measurement - in a laboratory using equipment that analyses the oxygen and carbon dioxide being breathed in & out by the subject)
- ✓ 12 min walk/run (estimate - with the use of norms and standards, performance on the tests allows an estimation of VO_2)
- ✓ 20 metre multistage beep test (estimate)
- ✓ 2 km Rowing ergometer test (estimate)

Oxygen Uptake

Oxygen uptake increases with exercise

- At rest 3-4 mL/kg/min
- Exercise 30-50 mL/kg/min

Average VO_2 max …..

- untrained males 42- 46 mL/kg/min
- untrained females 30 – 39 mL/kg/min

- Note the gender differences, due to heart, lung and body size for example

- Elite aerobic athletes, depending on their sport, can have VO_2 max readings of 50 – 85mL/kg/min

The main physiological aspects that determine the VO_2max are

- the size of the left ventricle (stroke volume),
- blood volume
- capillary density supplying the muscles
- other chronic adaptations of the aerobic energy system

Aerobic training ……..

- can increase a person's VO_2max by 15-20% depending on their initial fitness levels
- one's maximal oxygen uptake adapts, and detrains fairly quickly
- within a 12 to 18 months of aerobic training, a person can achieve their maximum possible VO_2max
- genetic make-up determines further improvements in VO_2max.
- VO_2can be best trained by using whole body type activities, using large muscle groups (that create more demand for oxygen) eg. running for 20-30 mins
- Training at intensities, (and below the anaerobic threshold) to avoid the interference by the anerobic energy system is desirable.
- VO_2max can be improved by cross training activities, and other whole body type activities, such as running and cycling

The speed developed at VO_2max - v VO2 max

The speed developed at VO_2max is termed vVO_2max, this is a function of VO_2max, and the efficiency of the technique used to convert the power developed to boat speed.

This is highly trainable and a much faster speed can be obtained for the same VO_2max when a powerful, coordinated and relaxed technique is used.

This efficiency and power is a function of the central nervous system and is determined by the muscle recruitment patterns of the stroke.

Resistance and explosive paddling, as well as high-speed movement, can improve one's vVO_2max.

Building an Aerobic Base

Planning training that assists in the development of the chronic adaptations of the body to exercise, particularly those that assist in the efficient use of the aerobic energy system cannot be underestimated. Having a good “aerobic base” is the foundation of other training and improvements.

Maximising the amount of distance covered in a training week, maximises training volume and contribute to building an aerobic base.

Building such a solid aerobic base takes a lot of time on the water, and an accumulation of seasons, to develop.

Not only does an aerobic base improve the aerobic power that can be produced, it also allows for better recovery from anaerobic training because recovery much depends on blood supply to the muscle.

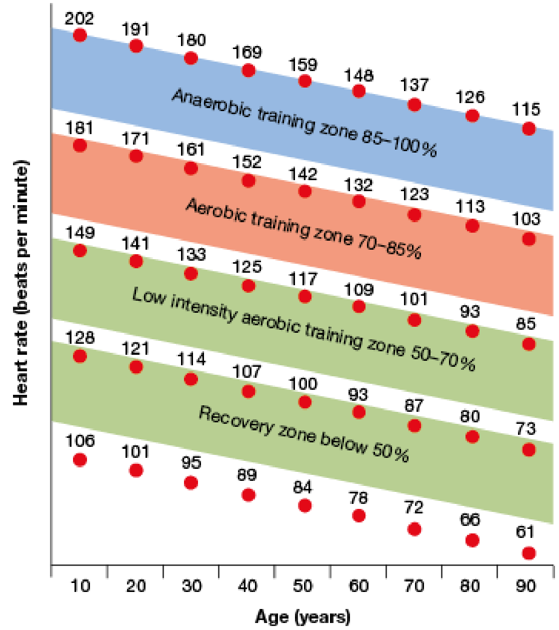
Therefore the better the aerobic base, the more quickly and better the anaerobic capacity can become (‘the bigger the base, the bigger the peak’).

TRAINING INTENSITY LEVELS

To be able to develop the physiological chronic adaptations of training, a well planned TRAINING PROGRAM using the appropriate TRAINING PRINCIPLES and TRAINING METHODS is desired.

INTENSITY is one such principle that, with the appropriate Training Method, can be manipulated to enable these beneficial chronic adaptations.

Several aspects can be used to determine intensity such as stroke rate, heart rate, boat speed or feeling.
The training zones detailed below are used in other sports and provide a guideline for intensity levels relevant to dragon boat.
These zones need to be communicated clearly between the coach and paddler.
It is therefore important that the paddlers understand how to achieve each intensity level and what it feels like.



Our Mission: To connect people with dragon boating across Australia

Please **turn up your volume** then click on the URL link below to view a short video of the Bioenergetic system.

When the video is completed please return and go to the next slide in this presentation.

https://youtu.be/446dZ1b9_4Y

Further Reading

Please click on the following link for additional reading material in relation to Recovery

https://www.ausdbf.com.au/ausdbf-courses/coachesforum/

Includes 2 articles:

- **Recovery during training cycles**
- **Recovery review – undertaken by the AIS**