Energy for Exercise

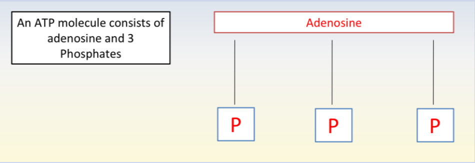
We need a constant supply of energy so that we can perform everyday tasks. The more exercise we do the more energy is required

The intensity and duration of an activity play an important role in the way in which energy is provided.

ATP – (Adenosine Triphosphate)

- **ATP -** The usable form of energy in the body

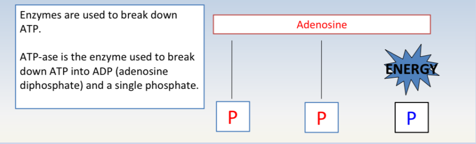
The energy from foods that we eat, such as carbohydrates, has to be converted into ATP before the potential energy in them can be used


An ATP molecule consists of adenosine and 3 Phosphates

ATP Breakdown

Energy is released from ATP by breaking down the bonds that hold this compound together

This type of reaction is an exothermic reaction

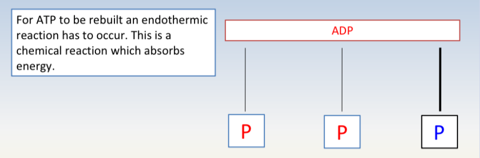

Enzymes are used to break down ATP.

ATP-ase is the enzyme used to break down ATP into ADP (adenosine diphosphate) and a single phosphate.

ATP Resynthesis

ATP within muscle fibres are used up very quickly (2-3 seconds) and therefore needs to be replenished immediately

Resynthesis of ATP is done through the joining of ADP and a single phosphate. This energy regeneration is only possible through one of three energy systems


For ATP to be rebuilt an endothermic reaction has to occur. This is a chemical reaction which absorbs energy.

Energy Systems

There are three energy systems that regenerate ATP:

- **ATP-PC system**
- **Glycolytic system**
- **Aerobic system**

Each energy system is suited to a particular type of exercise depending on the intensity and duration and whether oxygen is present

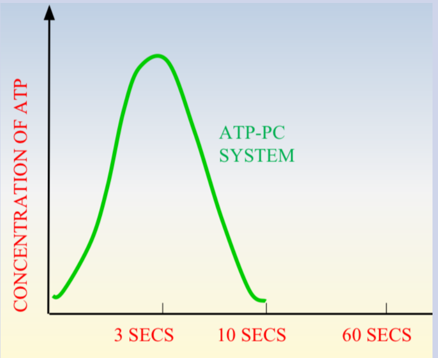
ATP – PC System

Depleted ATP stores trigger the release of creatine kinase which causes phosphocreatine (PC) to be broken down anaerobically

- **Phosphocreatine** - An energy-rich chemical produced naturally by the body, this compound is found in the sarcoplasm of the muscles

This rapid availability of PC is important for providing contractions of high power, such as in the 100 m or in a short burst of intense activity during a longer game i.e. a fast break in basketball

However, there is only enough PC to last for up to 10 seconds and it can only be replenished when the intensity of the activity is sub-maximal



Advantages	Disadvantages
- ATP can be regenerated rapidly - PC stores are replenished within 3 minutes - No fatiguing by-products - The ATP-PC system can be extended through the use of a creative supplement	- Limited supply of PC in the body - 1 ATP molecule regenerated for 1 molecule of PC - Regeneration can only take place in the presence of oxygen

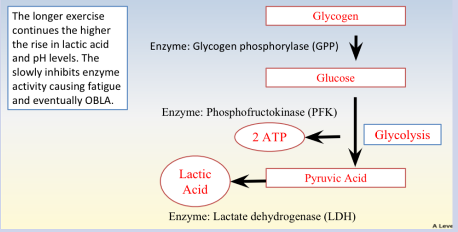
For every one molecule of PC broken down there is enough energy released to create one molecule of ATP

This is not very efficient system but it does have the advantage of not producing by-products and its use is important in delaying the onset of the lactic anaerobic system

This breaking down of PC to release energy is a coupled reaction

Glycoltic System

- **Anaerobic Glycolysis** - The process of glucose breakdown in the absence of oxygen which causes the production of pyruvic acid


The longer exercise continues the higher the rise in lactic acid and pH levels. The slowly inhibits enzyme activity causing fatigue and eventually OBLA.

Glycoltic ATP resynthesis will continue for up to 3 minutes but peaks at 1 minute This is particularly useful for cycling sprint events or a counter attack in football.

Advantages	Disadvantages
- ATP can be regenerated quickly due to fewer chemical reactions being needed - With oxygen present, lactic acid is converted back in to glycogen - This energy system is useful for producing an extra burst of energy	- Lactic acid is a by-product of this system - Only a small amount of energy is released from glycogen while under anaerobic conditions

Aerobic System

The aerobic system kicks in during low- to moderate-intensity activity as the arrival of sufficient oxygen enables continued energy production
The aerobic system utilises around 95 per cent of the potential energy in glucose through three distinct stages: Aerobic Glycolysis
Kreb's Cycle
Electron Transport Chain (ETC)

Applied Anatomy & Physiology

- Energy for Exercise , Recovery, Altitude and Heat

Aerobic Glycolysis

Aerobic glycolysis in the sarcoplasm converts glucose into pyruvic acid with the enzyme PFK catalysing the reaction

This releases enough energy to resynthesise two moles of ATP. Converting glycogen into glucose (by enzyme GPP) maintains this process for extended periods of time

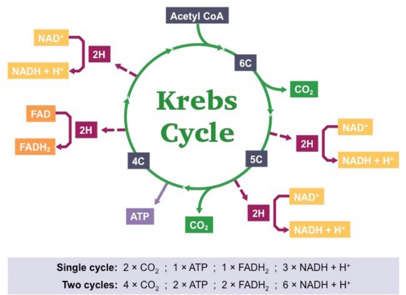
As oxygen is now in sufficient supply, the pyruvic acid is no longer converted intolactic acid. It goes through a link reaction catalysed by coenzyme A, which produces acetyl CoA. This allows access to the power house of the muscle cell, the mitochondria

Kreb's Cycle

- **Kreb's Cycle** - The second stage of the aerobic system producing energy to resynthesise 2 ATP in the mitochondrial matrix.

Acetyl CoA combines with oxaloacetic acid to form citric acid, which is oxidised through a cycle of reactions

Known as the Kreb's cycle, CO2, hydrogen and enough energy to resynthesise two moles of ATP are released. This process occurs in the matrix (intracellular fluid) of the mitochondria



Single cycle: $2 \times CO_2$; $1 \times$ ATP ; $1 \times FADH_2$; $3 \times NADH + H^+$
Two cycles: $4 \times CO_2$; $2 \times$ ATP ; $2 \times FADH_2$; $6 \times NADH + H^+$

Electron Transport Chain (ETC)

- **Electron Transport Chain (ETC)** - The third stage of the aerobic system producing energy to resynthesise 34 ATP in the mitochondrial cristae

The hydrogen atoms are carried through the electron transport chain along the cristae (folds of the inner membrane) of the mitochondria by NAD and FAD (hydrogen carriers), splitting into ions (H+) and electrons (H−)

Electron Transport Chain (ETC)

Hydrogen ions are oxidised and removed as H20
Pairs of hydrogen electrons carried by NAD (NADH2) release enough energy to resynthesise 30 moles of ATP and those carried by FAD (FADH2) release enough energy to resynthesise 4 moles of ATP. The overall energy yield of the ETC is 34 moles of ATP
When all three stages are combined, one mole of glucose yields 38 moles of ATP. This is a highly efficient and most preferable energy system used for long-duration low- to moderate-intensity activities such as marathons, triathlons and cross-country skiing.
The higher the performer's aerobic capacity, the faster oxygen will arrive in plentiful supply and the switch can be made to aerobic energy production.

The Aerobic System and FFAs

Glycogen stores are large and will fuel the aerobic system for a significant period of time. However, long-distance performers will want to preserve glycogen stores because they can be broken down both aerobically and anaerobically for higher-intensity sections of events
Triglycerides or fats can also be metabolised aerobically as free fatty acids (FFAs), providing a preferred and huge potential fuel store which conserves glycogen and glucose for those higher-intensity sections
Upon the release of lipase, an enzyme responsible for catalysing the breakdown of fats, triglycerides are converted into FFAs and glycerol. FFAs are converted into acetyl CoA and follow the same path through the Kreb's cycle and electron transport chain as pyruvic acid. FFAs produce more acetyl CoA and a higher energy yield and are therefore preferable for long-distance athletes whose events last more than an hour. However, FFAs require around 15 per cent more oxygen to metabolise and consequently the intensity of activity must remain low.

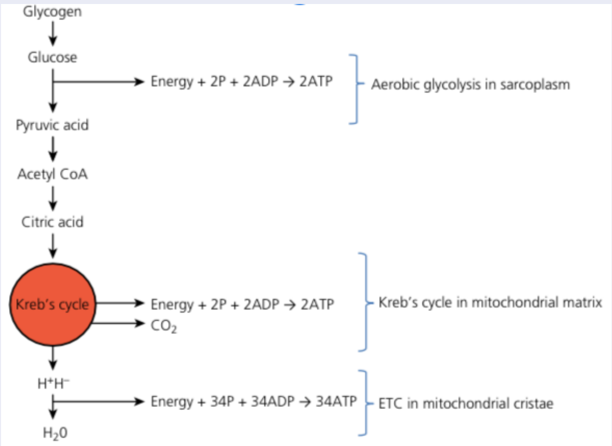


Figure 71.8 An overview of the aerobic energy system

Energy Systems

	ATP - PC	Glycolytic	Aerobic
Type of Reaction	Anaerobic	Anaerobic	Aerobic
Chemical or Food Fuel Used	Phosphocreatine (PC)	Glycogen / Glucose	Glycogen / Glucose & Triglycerides (FFAS)
Specific Site of Reaction	Sarcoplasm	Sarcoplasm	Sacroplasm, Matrix & Crista of Mitrochondria
Controlling Enzyme	Creatine Kinase	GPP, PFK & LDH	GPP, PFK, co – enzyme A and Lipase
ATP Yield	1 PC : 1 ATP	1 Glucose : 2 ATP	1 mole of Glycogen yield up to 38 moles of ATP (1:38)
Specific Stages within the System	PC -> P + C + energy (exothermic) Energy + P + ADP -> ATP (endothermic)	Anaerobic Glycolysis -> Glucose -> Pyruvate Pyruvate -> Lactic Acid	Aerobic Glycolysis, Krebs cycle and Electron Transport chain (ETC) Glucose + 6O2 + 6H2O + energy (exothermic) Energy + 38P + 38ADP -> 38ATP (endothermic)
By - Products	None	Lactic Acid	CO2 & H2O

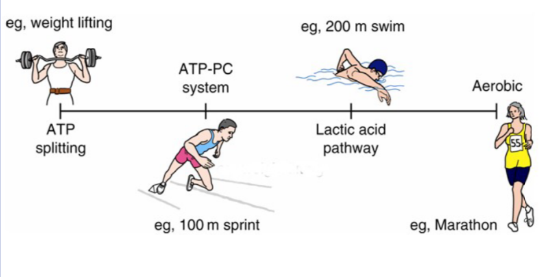
ATP Resynthesis during exercise of Differing Intensities and Durations

At rest we provide almost energy for ATP resynthesis using the aerobic system; however, when we start to exercise our demand for energy increases significantly and there may not be enough oxygen available to maintain sole aerobic energy production

Energy Continuum

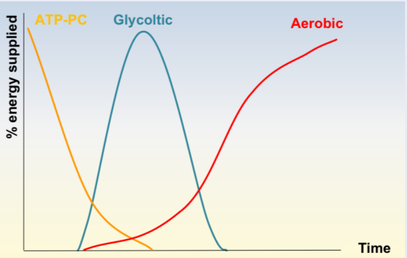
All the energy systems contribute during all types of activity but one of them will be the predominant energy provider
The intensity and duration of the activity are the factors that decide which will be the main energy system in use

E.G 800m Race
- ATP-PC System = start of race
- Aerobic System = majority of race
- Glycoltic System = sprint finish



Intermittent Exercise

- **Intermittent Exercise** - This is where the exercise intensity changes frequently i.e. a basketball player is required to walk, run, sprint and jump at various points in the game



The point at which an athlete moves from one energy system to another is known as a threshold. This depends on the exercise intensity and fuel available.

The ATP-PC/glycoltic threshold is the point at which the ATP-PC energy system is exhausted and the glycoltic system takes over

As a midfielder, performers would need to make short 3 second sprints to get free or beyond a defender (ATP-PC) but will also need the glycoltic system to make recovery runs back to help defend.

The glycoltic/aerobic threshold – this would occur when the ball is in phases of play away from the player. A performer will still track and scan players movement but at a lower intensity
Sufficient oxygen will be available throughout to allow for ATP resynthesis

Recovery Periods

Anaerobic sports such as rugby and basketball rely heavily on the ATP-PC system, athough the PC stores are depleted after 8-10 seconds they also recovery quickly

This energy system is 50% recovered in just 30 seconds and fully recovered after 3 minutes

Training must include the correct work to relief ratios. This will ensure sufficient oxygen supply and blood flow are able to break down the build up of lactic acid

Recovery periods also provide an opportunity to rehydrate, and replenish glucose stores in the form of glucose tablets, gels, bananas and isotonic drinks

Fitness Levels

An athlete with a high aerobic capacity will be able to utilise a large volume of oxygen

This will increase the intensity with which they can work at before OBLA is reached and fatigue sets in
Buffering capacity to lactic acid is also improved with higher fitness levels as is the ability to utilise FFA's before glycogen stores

Additional Factors

There are a number of other factors that decide energy system contribution:

- Position of Players – A goalkeeper will not use the same energy systems as an outfield player
- Tactics and Strategies – Man to man marking will raise the intensity and require a larger involvement of the anaerobic energy systems

Additional Factors

- Level of Opposition – Tougher opponents will push the demands of the game and rely on anaerobic systems for ATP resynthesis
- Size of playing space: A larger field (hockey field) will slow the intensity of the game down in comparison to a smaller space (netball court) which increases the demands of the anaerobic system

The Recovery Process

- **The Recovery Process** - Involves returning the body to the state it was in before exercise

The reactions that occur and how long the process takes depend on the duration and intensity of the exercise undertaken and the individual's level of fitness.

Post exercise the body is in a state of fatigue and enters a period of recovery. To do this, aerobic energy is required and is termed excess post-exercise oxygen consumption (EPOC)

- **Oxygen Deficit** - The amount of oxygen that the performer requires to complete an activity aerobically
- **Oxygen Debt** - Is the amount of oxygen needed to return the body to a resting state. Oxygen debt results from EPOC

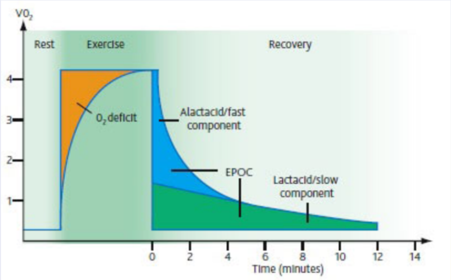
Excess Post – Exercise Oxygen Consumption (EPOC)

After strenuous exercise there are 4 main tasks that the body needs to be completed before the muscle can operate efficiently again

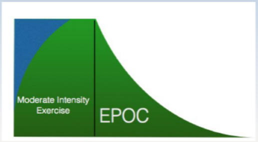
- Replacement of ATP and phosphocreatine (the fast component)
- Replenishment of myoglobin with oxygen
- Removal of lactic acid (the slow component)
- Replacement of glycogen

Oxygen deficit and EPOC can be plotted against time. There are two distinct stages during EPOC

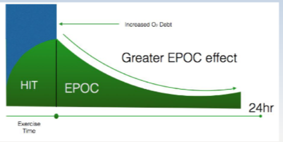
- The fast component of recovery
- The slow component of recovery



EPOC will always be present but the size of the oxygen deficit and EPOC will differ depending on the activity intensity and duration



Low intensity exercise



High intensity exercise

Low intensity exercise results in a small deficit limiting the use of the anaerobic energy systems and therefore lactic acid accumulation

Fast Component of Recovery

This first stage of EPOC recovery is also known as the alactacid component. The increased rate of respiration continues to supply oxygen to the body and myoglobin stores

EPOC helps replenish these stores and takes up to 2-3 minutes

Resynthesis of ATP and PC stores also occurs within the first 3 minutes of EPOC
After this time, phosphocreatine stores, are completely restored but 50% of PC can be replenished after only 30 seconds

Second Component of Recovery

This stage is also known as the lactacid component, it is the slowest of the replenishment processes and full recovery may take up to an hour, depending on the intensity and duration of the exercise
Post exercise respiratory rate (ventilation) and depth along with heart rate (circulation) remain high to aid removal of by-products such as CO2 and carbonic acid
Body temperature rises during exercise and will remain elevated during EPOC. This accounts for about 60% of the slow lactacid component of EPOC

Excess Post – Exercise Oxygen Consumption (EPOC)

Lactic acid (the slow component) can be removed in four ways….

Components of lactic acid removal	% Lactic acid involved
Pyruvic acid is oxidised (broken down) and re-enters the kreb's cycle to produce carbon dioxide, water and energy.	**65**
Converted into glucose and then stored in muscles/liver as glycogen. This process is called gluconeogenesis and glyconeogenesis.	**25**
Converted into protein	**10**

Performing a cool-down accelerates lactic acid removal because exercise keeps the metabolic rate of muscles high and keeps capillaries dilated. This means that oxygen can be flushed through, removing the accumulated by products

The stores of glycogen in relation to the stores of fat are relatively small
The replacement of glycogen stores depends on the type of exercise undertaken. It may take a number of days to complete the restoration of glycogen after a marathon
Eating a high-carbohydrate meal will accelerate glycogen restoration, and should be done within 1 hour post exercise

Work:Recovery Ratios

Training should adopt the correct work to rest balance depending on the energy system required

Training aim	Main energy system	Work:recovery ratio
Explosive strength & Speed (100m)	ATP-PC system	1:3+
High-intensity – Muscular endurance (800m)	Glycoltic system	1:2
Aerobic capacity / endurance (Marathon runner)	Aerobic system	1:0.5

Ways to Minimise the Affect Heat has on Performance

Pre-Event	During the Event	Post-Event
- Acclimatise to the temperature. 7-14 days of exposure will increase the body's tolerance to the humidity - Use cooling aids to delay the effect of high temperatures and dehydration. Some athletes use ice vests to do this	- Use pacing strategies to ensure an athlete does not exert themselves - Wear suitable clothing such as lightweight/breathable compression wear - Rehydrate as often as possible with isotonic solutions to replace fluid, glucose and electrolytes.	- Use cooling aids after the event such as towels, fans and an ice baths to return core temperature - Replace lost fluids and glycogen stores with isotonic solutions

Effects of Heat on Cardiovascular System	Effects of Heat on Respiratory System
- Increased blood flow to capillaries close to the skin - Decreased blood volume, venous return, stroke volume, cardiac output and blood pressure	- Dehydration and drying of the airways causes difficulties in breathing - Increased frequency of breathing to maintain oxygen consumption - High levels of humidity cause irritations of airways

Training Implications of Recovery

Warm Up Thoroughly
Reduces O2 deficit by increasing O2 supply to working muscles and ensure myoglobin stores are full

Active Recovery (cool down)
Using an active recovery maintains respiratory and heart rates and flushes the muscles and capillary beds with oxygenated blood flow. This also aids removal of lactic acid is quicker. Intensity of cool down depends on individual but moderate (approx 35%) is best.

Monitor Training Intensities
This will ensure performers avoid OBLA and maintain quality of training

Cooling Aids
Ice baths can be used to lower the muscle and body temperature and reduce the demand on the slow lactacid component.

Strategies and Tactics
A coach should use timeouts and substitutions strategically to allow for lactic acid removal and ATP resynthesis

Nutrition
The correct pre, during and post match nutrition is vital to maximise fuel stores, delay the onset of fatigue and aid recovery

Exercise in the Heat

- **Thermoregulation** - This is the process of maintaining core body temperature

It is important to acclimatise and enable the body to modify the control systems that regulate blood flow to the skin

Thermoreceptors in the body sense changes in temperature and cause the medulla oblongata to initiate a series of actions. Heat is transported to the surface of the skin by the blood. The blood vessels vasodilate and allow heat to be lost through evaporation

Exercise in the Heat

When the body is dehydrated, total blood volume decreases. More blood is redirected to the skin, so the amount oxygen available to the working muscles is reduced

- **Hyperthermia –** A rise in core body temperature of several degrees can greatly affect performance

This is common if an athlete pushes themselves too fast, for too long or in hot humid conditions

- **Cardiovascular Drift** - During prolonged exercise in a warm environment the body will experience an upward 'drift' in heart rate despite the intensity of the exercise remaining the same

Exercise at Altitude

The percentage of oxygen (O2) in the air is the same at sea level and at altitude. However, the partial pressure of oxygen decreases as altitude increases. This causes a reduction in the diffusion gradient between the air and the lungs and between the alveoli and the blood
As a result, the diffusion gradient at sea level (Wembley, London) is 119 (159 – 40 = 119mmHg) compared with that at stadiums in Mexico city (115-40 = 75mmHg), this reduction severely affects oxygen diffusion into the blood stream. As a result, haemoglobin is not fully saturated at altitude, which results in a lower oxygen-carrying capacity of the blood.

Altitude	Venue	pO2 (mmHg)
Sea level	Football – Wembley, London	159
1609 m	NFL – Denver Broncos (Mile high stadium, Colorado)	132
2240 m	Mexico City football stadia	115
9000 m	Summit of Everest	47

Advantages	Disadvantages
Increase in red blood cell production due to release of erythropoietin.	**Expensive to setup due to travel and accommodation costs.**
Increased concentration of haemoglobin	**Altitude sickness**
Better O2 transport	**Training is tough and requires high levels of motivation.**
Altitude training effect will last for up to 2 weeks. Useful when preparing for competition.	**Benefits can be lost quickly so will no benefit competition all year round.**

As less oxygen is delivered to working muscles there is an earlier onset of fatigue. This results in a decrease in aerobic energy production and performance

The body reacts by:

1. Breathing frequency increases both at rest and during exercise
2. Blood volume decreases and increases the density of red blood cells
3. Stroke volume decreases which causes heart rate to increase to compensate

- **Acclimatisation –** The process with which an athlete goes through to adapt to the environment

Reduction in VO2 max places a greater strain on the aerobic energy system leading to earlier lactic acid production