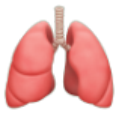

Respiration

Describe the role of NAD and FAD

- Organic molecules such as glucose oxidised during glycolysis, link reaction and Krebs Cycle and the electrons and protons from oxidation are transferred to the coenzyme NAD+ and FAD in order to reduce them to NADH and FADH2 respectively
- They serve as mobile electron and proton car to carry the high energy electrons and protons from these organic molecules to the electron transport chain and thus re-oxidising themself
- The high energy electrons in NADH and FADH2 are used to reduce electron carriers of the electron transport chain and the coenzymes reoxidises themself to form NAD+ to FAD
- The high energy electrons release energy as they are passed down the electron transport chain in order to provide energy for the electron carriers to actively pump protons from the mitochondrial matrix to the inter membrane space against its concentration gradient, establishing a proton gradient due to the impermeability of the inner mitochondria membrane, which is important for ATP synthesis as this series of redox reactions is coupled to phosphorylation of ADP to form ATP
- Re-oxidation of NADH and FADH2 allows regeneration of NAD+ and FAD, allowing it to pick up more protons and electrons from Krebs cycle, link reaction and glycolysis in order to continue the reactions
- Each reduced NAD yields 3 ATP
- Each reduced FAD in the matrix yield 2 ATP through oxidative phosphorylation
- During anaerobic respiration, re-oxidation of NaDH allows regeneration of NAD during fermentation to allow glycolysis to continue in order to produce ATP in absence of oxygen

- The high energy electrons from NADH and FADH2 combines with oxygen, a final electron acceptor to form water
- During anaerobic respiration, electrons from NADH reduces pyruvate in the presence of lactate dehydrogenase to form lactate amd it also reduces ethanal in the presence of CO2 with ethanol

Describe main stages of Krebs cycle

- Takes place in the mitochondrial matrix and when oxygen is present
- Acetyl coA (2C) produced during the link reaction combines with oxaloacetate(4C) to form citrate (6C)
- Citrate is decarboxylated and dehydrogenated to form, alpha-ketoglutarate (5C) and NADH
- Each decarboxylation results in a loss of carbon to form CO2
- Regeneration of oxaloacetate involves decarboxylation and dehydrogenation to yield 2 NADH and 1 FADH2 and 1 CO2
- Electrons from glucose transferred to electron carriers NAD and FAD in order to reduce them
- NAD+ + 2H+ + 2e → NADH + H+ (or reduced NAD)
- FAD + 2H+ + 2e → FADH (or reduced FAD)
- 1 ATP is also produced through substrate-level phosphorylation during this regeneration process
- All carbon in glucose lost as carbon dioxide
- Overall,1 molecule of glucose forms 6 NADH, 2 FADH2 and 2 ATP as Krebs cycle occurs twice per glucose molecule.

How ATP is produced during anaerobic respiration / why does anerobic respiration only yield a small amount of ATP/ why only glycolysis occurs in anaerobic respiration / why does it yield a small amount of ATP

- takes place in absence of oxygen which serves as a final electron acceptor in electron transport chain
- Without oxygen, no final electron acceptor for oxidative phosphorylation, both link reaction and Krebs cycle **subsequently** stop as NAD+ cannot be regenerated from NADH in mitochondrion as NADH and FADH2 unable to donate its electrons to the electron transport chain hence no electron carriers to be regenerated,
- movement of electrons along etc inhibited, no more electrochemical proton gradient and hence ATP cannot be synthesised by oxidative phosphorylation, no proton pumping
- Hence, glucose not completely oxidised to form CO2 and water and energy is still trapped in the ethanol/lactate
- Anaerobic respiration takes place in the cytoplasm of the cell via only glycolysis to produce a net of 2 ATP molecules per glucose via substrate level phosphorylation for each glucose molecule oxidised
- Pyruvate undergoes alcoholic fermentation whereby it is decarboxylated to ethanal and then reduced by pyruvate dehydrogenase and pyruvate decarboxylase to ethanol and carbon dioxide respectively with the regeneration of NAD+ in yeast
- In mammal, lactate fermentation occurs where NAD+ regenerated as electrons in NADH is used to reduce pyruvate with lactate dehydrogenase to lactate
- NAD+ regenerated in both processes ensures steady supply of NAD is used for glycolysis to continue hence only glycolysis occurs only

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Role of oxygen in aerobic respiration

- Acts as a final electron acceptor at the end of electron transport chain where it will combine with electrons and protons to form water
- By removing electrons, oxygen re-oxidises electron transport chain so that NADH and FADH2 can continue to donate electrons to the chain, thereby allowing oxidative phosphorylation to continue to produce ATP

- This allows regeneration of NAD+ and FAD allowing them to pick up more electrons and protons from glycolysis, link reaction and Krebs cycle to keep them going

Why more glucose is required during anaerobic respiration/ less glucose used in aerobic respiration?

- Under aerobic conditions, complete breakdown of glucose produces 38 ATP molecules per glucose molecule compared to 2 AtP molecules in anaerobic conditions
- Under anaerobic respiration, 19 glucose molecules will be needed to generate the same amount of energy that 1 glucose can produce in aerobic respiration
- Under aerobic conditions, link reaction and Krebs cycle produce NADH that will be oxidised and hence regenerated by the electron transport chain during oxidative phosphorylation, generating additional ATP
- However, under anaerobic conditions, glycolysis only produces a net of 2 ATP molecules for each glucose molecule oxidised and NAD is only regenerated through fermentation process to allow only glycolysis to continue. Link reaction and Krebs cycle are unable to continue due to absence of oxygen, a final electron acceptor, to regenerate NAD and FAD so electrons remain in NADH and FADH2 and unable to carry more electrons from these reactions.

Effect of ATP on PFK activity

- High ATP concentration leads to an inhibition of PFK activity
- ATP acts as an allosteric inhibitor and bind to allosteric site of PFK, inducing a conformational change in the 3D conformation of PFK such that substrate is no longer complementary in shape and charge to active site, stabilises inactive conformation of PFK, reducing affinity for fructose 6-phosphate
- Decreases rate of glycolysis as lesser glucose molecules converted to substrate, lesser pyruvate formed

Why is anaerobic respiration unsustainable for the muscles in the long run?

- Anaerobic respiration only yields a net gain of 2 ATP molecules per molecule of glucose peer glycolysis which is an inefficient form of energy release as compared to 38 ATP per glucose molecule in aerobic respiration which is not enough to provide great energy demands and can deplete energy storage of glycogen and fats
- Under anaerobic conditions, lactate fermentation occurs where pyruvate molecules converted to lactic acid to regenerate NAD from NADH in order for glycolysis to continue
- Continuous production of lactic acid causes accumulation of lactic acid in muscle causing muscle fatigues and muscle aches

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Outline the process of aerobic respiration

- occurs when food substances such as carbohydrates are oxidised to provide energy, protons and electrons in order to produce ATP
- Oxygen is required for the complete oxidation of food substances and to produce large amounts of ATP
- Glycolysis occurs in the cytoplasm of the eukaryotic cell
- Phosphorylation of glucose involves in the initial investment of 2 ATP molecules which phosphorylate glucose molecules to form fructose-1, 6-bisohosphate catalysed by phosphofructokinase which then cleaves to from 2 molecules of glyceraldehyde-3-phosphate (G3P) (3C)
- G3P undergoes oxidation by dehydrogenatiom to form glycerate-3-phosphate, causing NAD+ to be reduced to NADH, Substrate level phosphorylation of ADP forms 4 ATPs per glucose molecule hence each glucose molecule yields net gain of 2 ATP, and 2 NADH
- 2 pyruvate molecules are formed per glucose molecule
- In Link reaction, pyruvate is actively transported into the matrix of the mitochondria via transport proteins and undergoes oxidative decarboxylation and combines with coenzyme A to form Acetyl coA (2C)
- CO_2 is release pad and NAD+is reduced to NADH in this process
- Each glucose molecule yields 2 ATP, 2 NADH, 2CO_2 and 2 Acetyl coA

- Krebs cycle occurs in the matrix of mitochondria
- Acetyl coA combines with oxaloacetate (4C) to form citrate (6C)
- Citrate decarboxylated and dehydrogenated to form alpha-ketoglutarate (5C) and NaDH, resulting in a loss of carbon in the form of a carbon dioxide
- Regeneration of oxaloacetate involves in 1 decarboxylation step and 3 dehydrogenation step to yield 2 NADH, 1 FADH2 and 1 CO2
- High energy electrons originally from glucose molecule transferred to electron carriers NAD+ and FAD to form NADH and FADH2
- 1 ATP is also produced through substrate level phosphorylation during the regeneration process
- Overall, 1 glucose molecule produces 6 NADH, 2 FADH2, 4CO2, and 2ATP
- Oxidative phosphorylation occurs on the folds of the inner membrane of mitochondria called Cristae
- NADH donates electrons to the first electron carrier of the ETC found on cristae
- The electrons carriers alternate between reduced and oxidised states as they accept and donate electrons and each successive carrier has a higher electronegativity
- Each FADH2 donates electrons at a lower level and hence generates 2 ATP compared to 3 ATP by NADH
- Electron transport through the series of carriers is coupled to the active pumping of H+ into the intermembrane space against its concentration gradient. Since the phospholipids are impermeable to protons, it allows a proton gradient to be established across the mitochondria membrane allowing protons to diffuse back into matrix via ATP synthase complex, phosphorylating ADP to ATP
- This process is known as a chemiosmosis and produces 90% of ATP during aerobic respiration with oxygen as the final electron acceptor having the highest electronegativity

How is the mitochondria adapted for oxidative phosphorylation

- It has cristae which increases the surface area to hold electron carriers and ATP synthase for ATP synthesis via oxidative phosphorylation
- It is a double membrane organelle where the inter-membrane space of the mitochondrion allows protons to accumulate as a temporary energy store before it is used to form ATP at the ATP synthase
- The impermeablility of the inner mitochondrion membranes to protons allows the electrochemical proton gradient to be maintained, serving as a source of potential energy for ATP synthesis during chemiosmosis
- The linear arrangement of electron carriers in the inner mitochondrial membrane enables more efficient electron transport

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Why are fatty acids not used more in earlier stages of long-distance run?

- More time needed to convert fatty acids into energy
- Lipase will need to breakdown fats to release fatty acids followed by oxidation of fatty acids to from Acetyl-CoA before energy can be released

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Explain effects of reduced oxygen on ATP production

- Reduced in oxygen lowers number of final electron acceptors
- Fewer electrons can be transferred through the ETC down an electrochemical gradient
- Less protons pumped across inner mitochondrial membrane into the intermembrane space, leading to smaller proton gradient
- Less oxidative phosphorylation can occur, lesser ATP production
- Anaerobic respiration may be switched on if low oxygen cannot meet demands of cells To keep synthesising ATP
- Lactate fermentation allows for regeneration of NAD from NADH to allow glycolysis to keep producing ATP

Role of oxygen

- acts as a final electron acceptor at the end of the electron transport chain, combining with H+ and electrons to form water in matrix
- By removing electrons, oxygen reoxidises the ETC so that NADH and FADH2 can continue to donate electrons to the chain and maintain flow of electrons along ETC allowing oxidative phosphate to continue to produce ATP
- In absence of oxygen, coenzymes NAD and FAD cannot be regenerated to accept more H atoms from link reaction and Krebs cycle and so these reactions and oxidative phosphorylation eventually stop

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Why does aerobic respiration start after an amount of time

- Time needed for increase uptake for oxygen
- Ensure enough oxygen l to act as a final electron acceptor in ETC to produce enough ATP to provide energy to respiring muscle cellls

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Why does rate of utilisation of glucose decrease under anaerobic respiration

- Under anaerobic respiration 2 ATP molecules produced compared to 38 ATP molecules in aerobic respiration
- Hence under anerobic conditions, 19 glucose molecules needed to generate the same amount of energy as aerobic respiration
- Under aerobic conditions, link reaction and Krebs cycle produce NADH that will be oxidised and hence regenerated by ETC during oxidative phosphorylation generating additional ATP
- However under anerobic conditions, glycolysis only produces a net 2ATP molecules for each glucose molecule oxidised and NAD is only regenerated through fermentation to allow glycolysis to continue, hence lesser NAD is formed and lesser glucose is utilised