Chapter 11.5

Muscle Energy and Metabolism

How ATP is created throughout a race?

Muscle Metabolism

Two metabolic pathways synthesize ATP

1) Anaerobic fermentation (glycolysis)

Enables cells to produce 2 ATP // no oxygen required // fast // occurs in myoplasm // Called fast glycolytic

Glucose (6 carbons) metabolized to two pyruvate molecules (3 carbon each) // when oxygen not available two lactic acid molecules produced instead of the pyruvate. // The anaerobic end product is toxic lactic acid /// believed to be factor in muscle fatigue

If oxygen is available, then a carbon is removed from pyruvate to make acetyl and attached to Co-A. Acetyl-CoA then enters the mitochondria. // This starts the Kreb's Cycle and Electron Transport Chain mechanism.

Muscle Metabolism

2) Aerobic respiration (Krebs Cycle also called Citrus Acid Cycle) and the Electron Transport System (ETS)

Takes place in the mitochondria //   makes a lot of ATP // requires oxygen // toxic end product CO_2

Produces H+ (acid) but oxygen combines with H+ (called metabolic water)

Produces more ATP   // glycolysis = 2 vs Kreb's Cycle = 36 to 38

Kreb's cycle reduces FAD and NAD / these reduced co-enzymes are then oxidized via electron transport system

Reduced co-enzymes transfer electrons to ETS /// electrons produce most of the ATP as the electrons pass through ATP Synthetase

Two ADP are directly phosphorlated within mitochondria during each "Krebs Cycle

How ATP is created throughout a race?

A muscle fiber will use different amounts of oxygen and glucose when at rest vs walking vs running.

When you exercise you need more ATP and will need more oxygen and glucose to produce this extra ATP.

The respiratory system, endocrine system, and cardiovascular system must increase their fictions to deliver the glucose and oxygen to the more active muscle fibers.

How ATP is created throughout a race?

As soon as you start to run, the demand for more oxygen and glucose increases immediately, however.

The respiratory, endocrine, and cardiovascular systems responds slower.

Time is required before the necessary amount of oxygen and glucose is delivered to the muscle fiber.

What mechanisms compensate for this gap in energy to support muscle function?

How ATP is created throughout a race?

How are muscle fibers able to “bridge” this time between the amount of ATP used before the start of the race and the amount of ATP needed when running?

This dynamic problem also occurs between the resting state and the walking state.

Similar events occur but the duration of the events differ between rest and the walking or running states.

ATP Metabolism

ATP is made "on demand" to power muscle fiber contractions. ATP is not stored. // once made it last less than one second (our benchmark)

At the start of exercise......

The cardiovascular system needs to increase cardiac output after you start to exercise.

The respiratory system needs to increase ventilation rate.

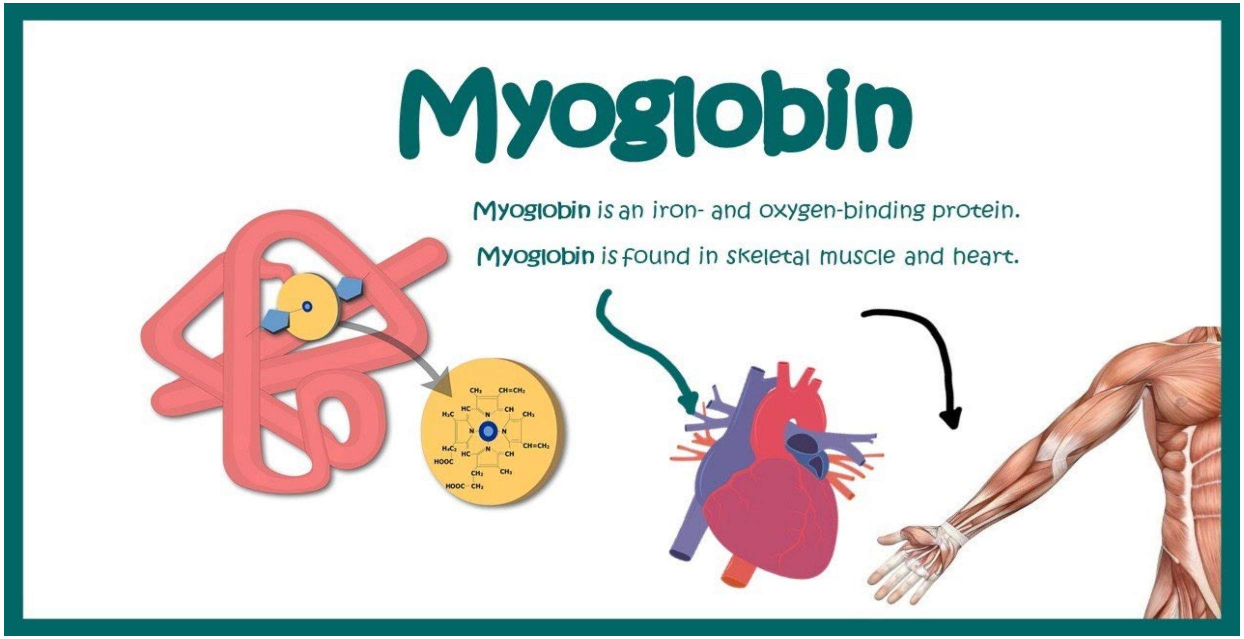
The endocrine system needs to release glucagon to regulate liver to release glucose into the blood.

These three events will take several seconds.

How do muscle fibers make "more ATP" when you start to walk or run?

1) Myoglobin stores oxygen in the sarcoplasm. This source of oxygen is used to support aerobic respiration in the mitochondria when blood oxygen levels drops rapidly, like when you start to exercise. But only a couple seconds of energy.

2) Muscle fibers store a small amount of glycogen in the sarcoplasm. This is used when blood glucose levels drop. Used by glycolysis. Again, only a few seconds.



Hemoglobin transports oxygen in RBC to the skeletal muscle

Oxygen diffuses from blood to muscle fiber's mitochondria where ATP is made

Any extra oxygen not needed to produce ATP maybe stored in the sarcoplasm attached to myoglobin // very small amount of oxygen

When oxygen levels in blood do not meet the MF oxygen requirement for ATP production, MF will use the oxygen attached to myoglobin so mitochondria may prolong ATP production. // Myoglobin’s oxygen provides only a second or two of function

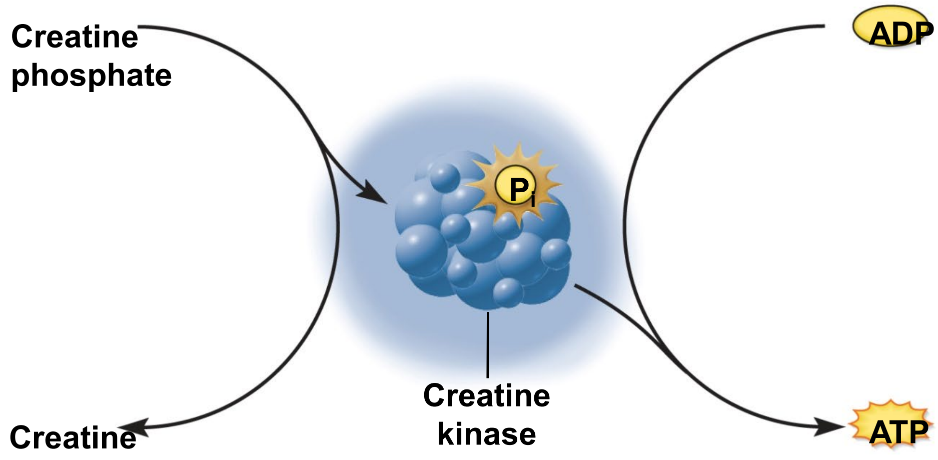
How do muscle fibers make “more ATP” when you start to walk or run?

3) ATP is constantly being made in the sarcoplasm by glycolysis. Glycolysis requires no oxygen and produces a small amount of ATP (only 2ATP). This ATP must be used immediately and last for less than a second. Another problem with anaerobic fermentation (glycolysis) is the accumulation of lactic acid. This will become a limiting factor for muscle contraction.

4) The phosphogean system is used to store ATP's energy. This system transfers ATP's high energy third phosphate to creatin to form creatin phosphate and ADP.

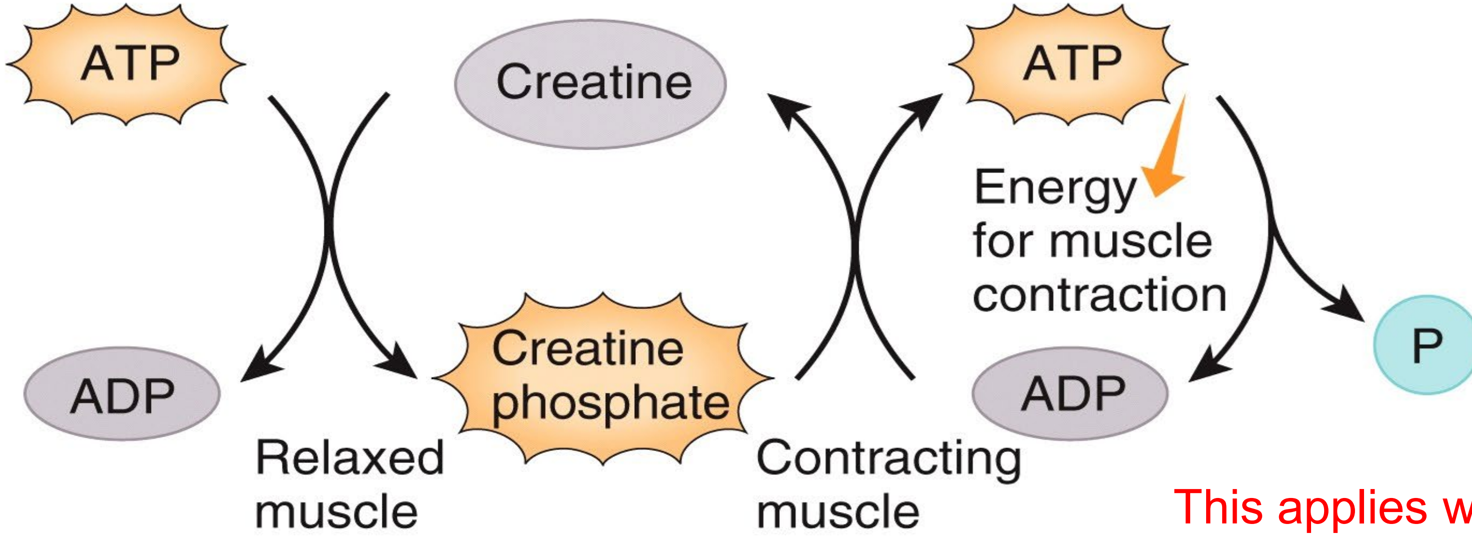
When a muscle fiber needs ATP, creatin phosphate may re-phosphorylate ADP to ATP. (how muscle fiber may store energy) Muscle fibers store about six seconds worth of energy in the form of creatin phosphate.

Creatine Phosophate



In the resting state, excess ATP can not be stored. However, if the muscle fiber has ATP not required for immediate use, the muscle fiber may transfer ATP's high energy phosphate to another molecule, creatine phosphate.

At a later time, when muscle fiber needs more ATP, creatine phosphate maybe used to phosphylate ADP back to ATP.



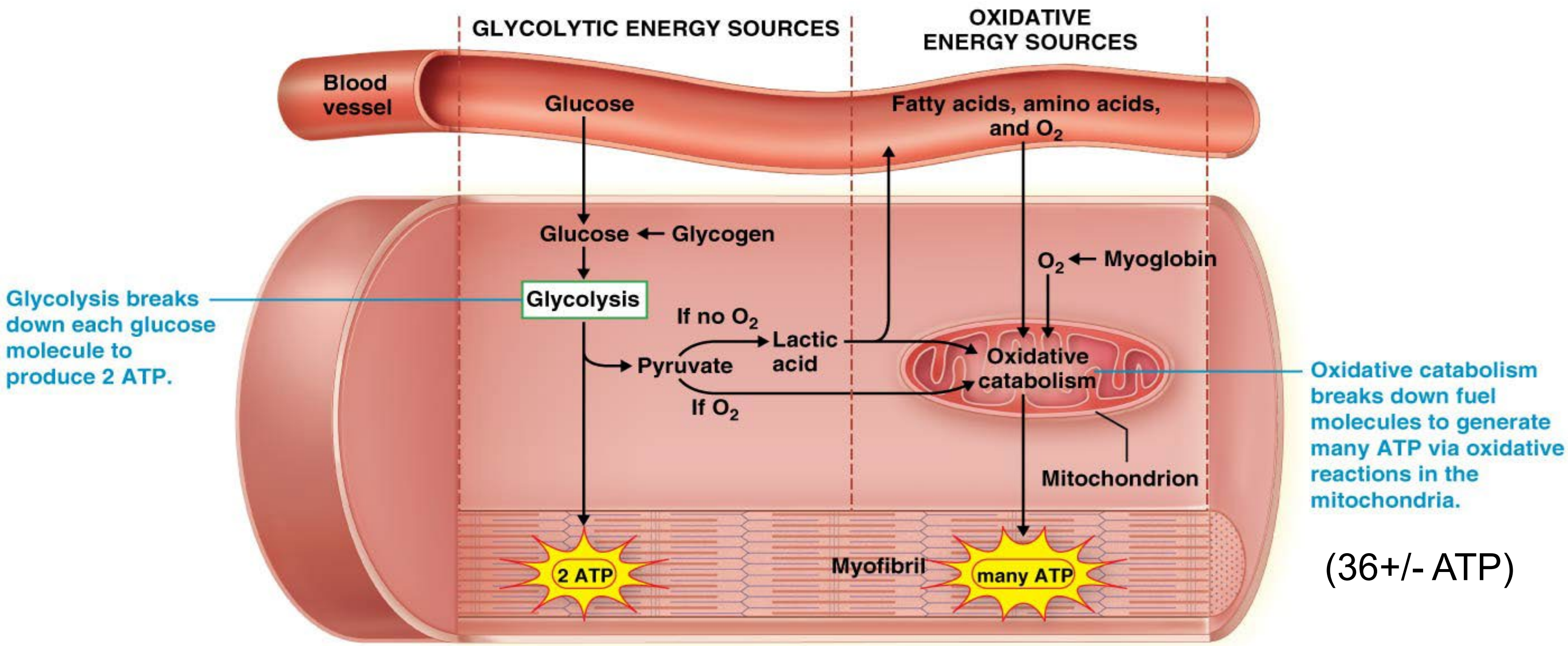
Duration of energy provided: 15 seconds

This applies when you start to walk. But if you start by "running" then CP-ATP may last only 2 to 3 seconds

(a) ATP from creatine phosphate

Now the creatine phosphate (phosphogen system) may supplement ATP production after myoglobin is depleted of oxygen .

Sources of energy for muscle fibers.

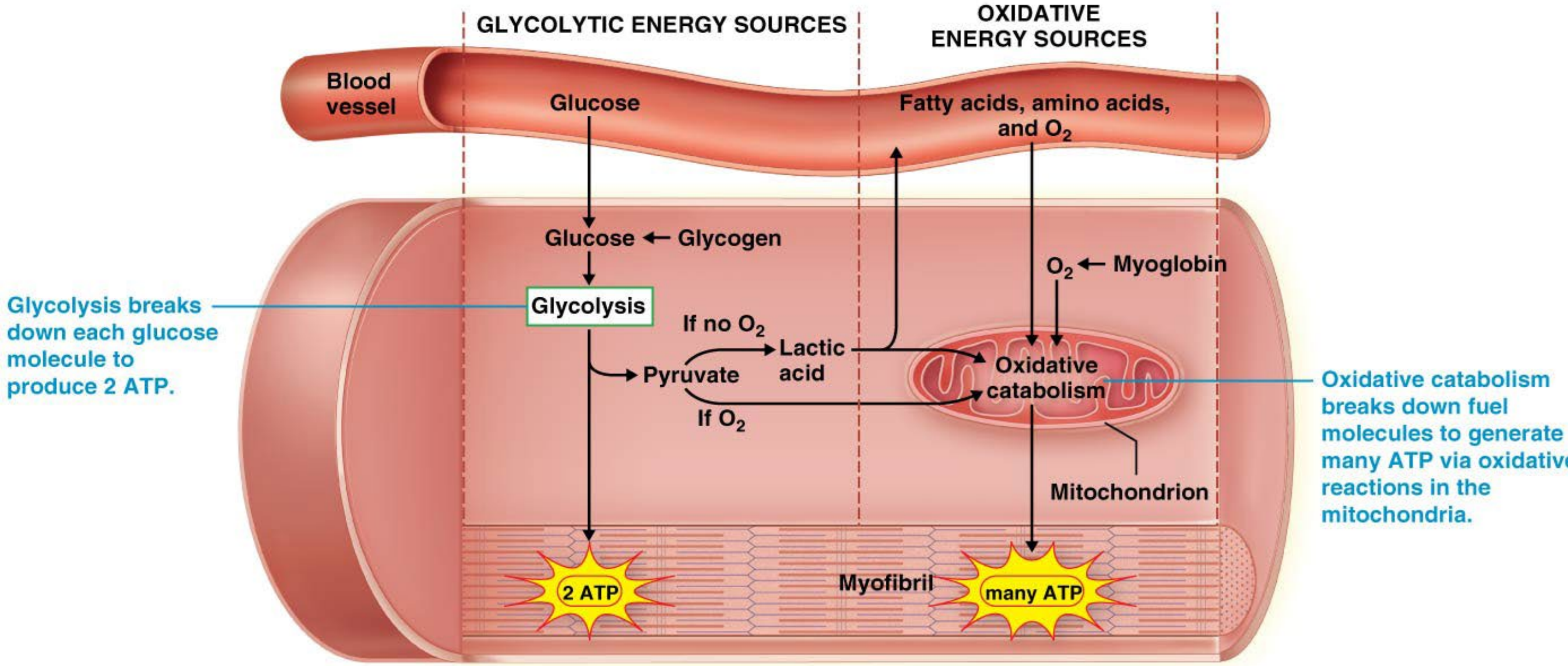


(36+/- ATP)

(b) Glycolytic and oxidative energy sources

When at rest, the blood supplies enough oxygen and glucose to meet the muscle fiber's ATP requirements. This requires a coordinated effort by the endocrine (glucose), respiratory (oxygen), and cardiovascular (transport) systems .

When you start to walk or exercise, MF demand for glucose/oxygen increases. There is not enough glucose/oxygen in the blood. Endocrine, respiratory, and cardiac functions will all need to increase. This will take time. <u>How will MF bridge the energy gap between the resting state and when you start to walk or run?</u>



(b) Glycolytic and oxidative energy sources

Anaerobic fermentation produces lactic acid

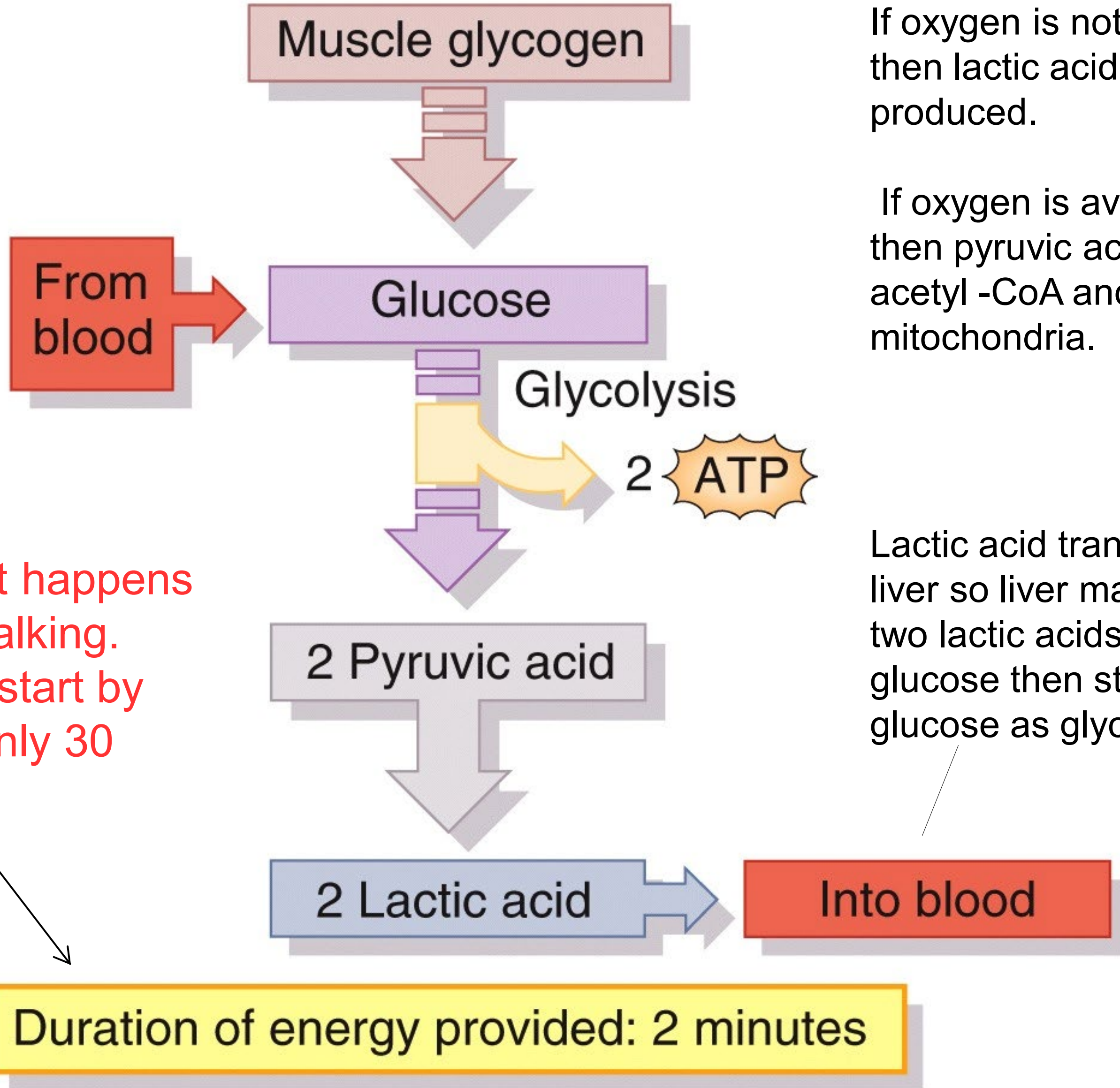
Lactic acid becomes a limiting factor for glycolysis as an energy source.

As lactic acid concentration increases in the sarcoplasm, muscle fatigue reduces ability of the muscle fiber to contract.

Anaerobic Glycolysis

If oxygen is not available, then lactic acid is produced.

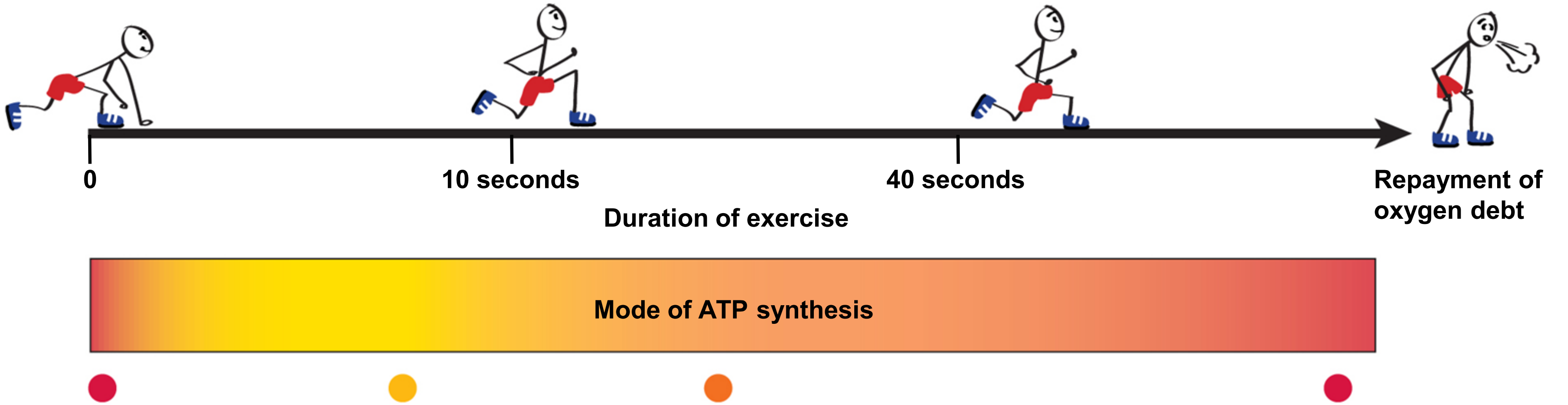
If oxygen is available, then pyruvic acid becomes acetyl -CoA and enters the mitochondria.



Lactic acid transported to liver so liver may convert two lactic acids into glucose then store glucose as glycogen.

This shows what happens when you are walking. However, if you start by “running” then only 30 seconds +/-

Modes of ATP Synthesis During Extreme Exercise



ATP in cytosol plus aerobic respiration using oxygen from Myoglobin 1 to 2 seconds

Phosphagen system another 6 to 8 seconds

Catabolize sarcoplasmic glycogen using glycolysis // lactic acid concentrations increase // after 30 seconds lactic acid causes muscle fatigue

Aerobic respiration is now possible due to increased cardiopulmonary functions able to supply necessary glucose and oxygen /// reached after 40 sec

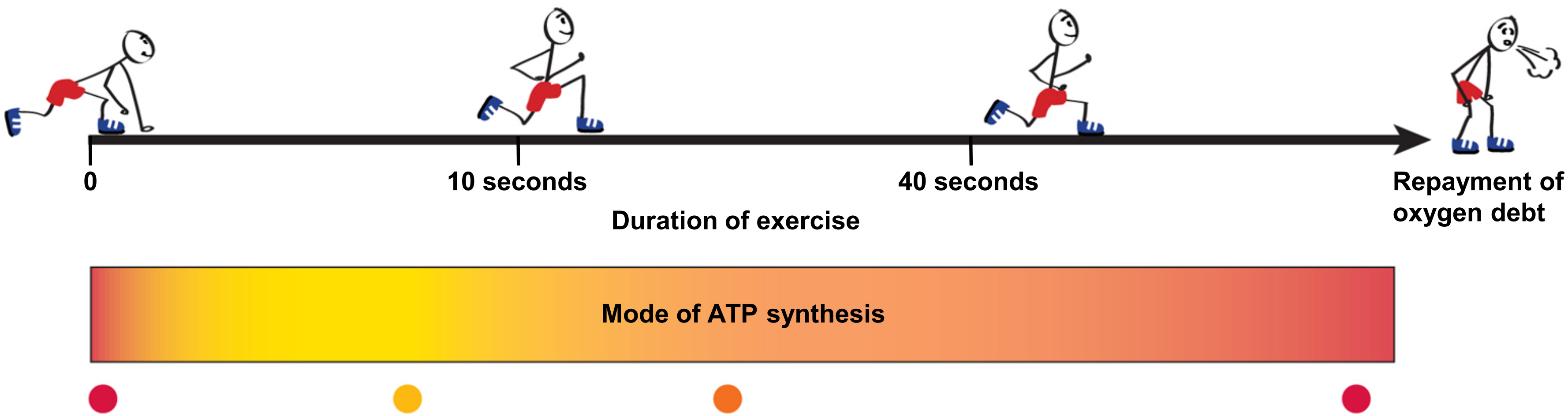
After race post exercise oxygen consumption remains high so the ATP "borrowed" at the start of race may now be replaced.

At rest we oxidize fatty acids to supply energy for our skeletal muscles (note: our brains continue to oxidize glucose / brain cells and RBCs only ferment glucose)

As level of activity increases, skeletal muscles will shift from fat to glucose as an energy source.

Only after glucose reserves are exhausted will we shift back to fat metabolism

Long-Term Energy Needs



After you start the race, after 40 seconds of running …….

Respiratory and cardiovascular systems "catches up" to the energy demands of skeletal muscles

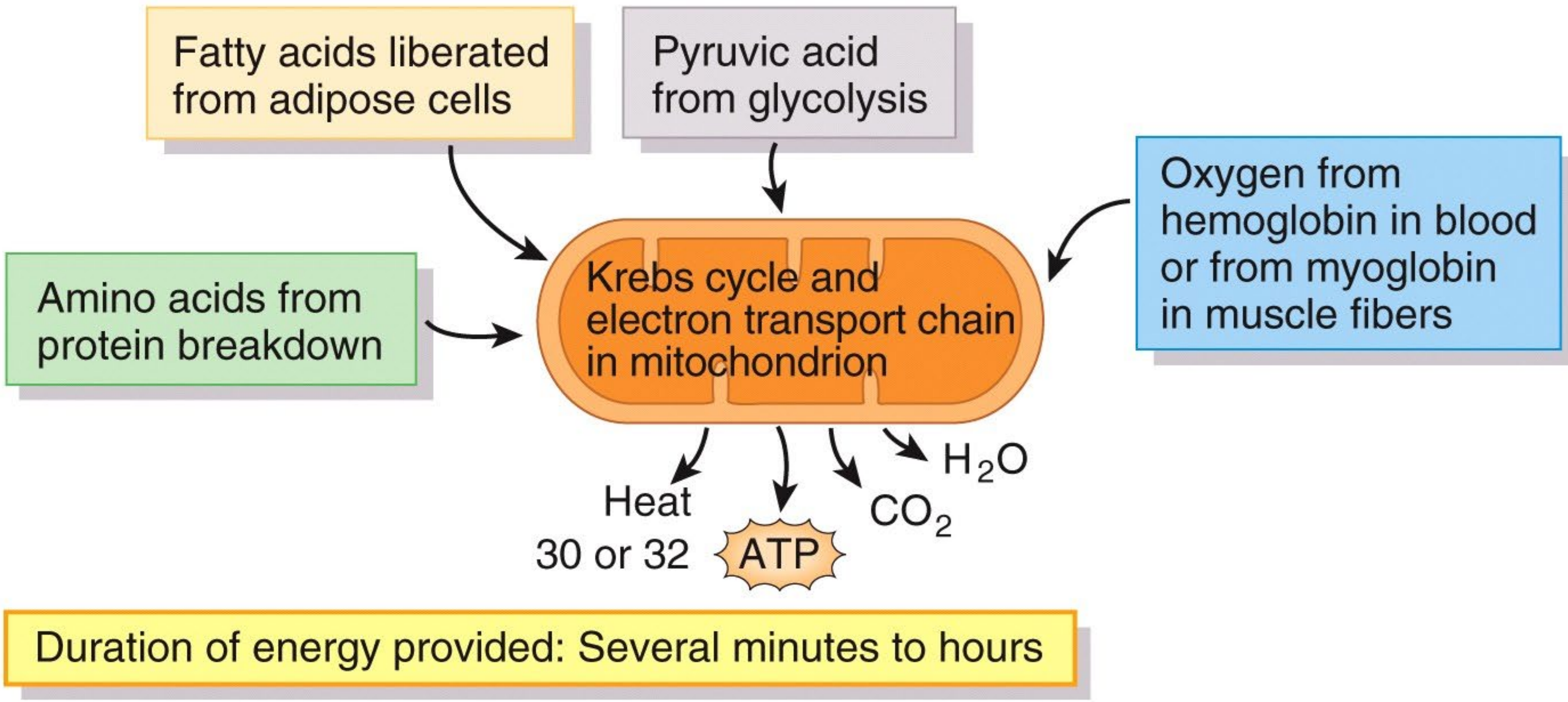
But muscle fibers have accumulated large amount of lactic acid

Now cardiorespiratory system is able to deliver enough oxygen to meet the muscle's oxygen requirement for aerobic respiration /// mitochondria able to make enough ATP to sustain muscle contractions.

Limiting factor now becomes conditioning and amount of stored glycogen and fat.

Aerobic Respiration

Reduced molecules are modified so they may enter the Kreb's cycle at different entry points. This allows for alternative fuel sources when glucose is not available.



What is Oxygen Debt?

Why does heavy breathing continue after you stop strenuous exercise?

Excess post-exercise oxygen consumption (EPOC) /// the difference between the resting rate of oxygen consumption and the elevated rate following exercise.

Typically, about 11 liters extra is needed after strenuous exercise

Oxygen debt occurs because we need to replace the ATP consumed to restore myoglobin and replenish CP

Oxygen Debt

Oxygen is needed more than current muscle activity for the following reasons:

Replace oxygen to the myoglobin // depleted in the first minute of exercise

- oxygen bound to myoglobin and blood hemoglobin
- oxygen dissolved in blood plasma and other extracellular fluid
- oxygen in the air in the lungs

Replenishing the phosphagen system

- Synthesize extra ATP to replace phosphate “borrowed” from creatine-phosphate at the start of the race

- Oxygen debt also called post exercise oxygen consumption.

Oxygen Debt

Furthermore, additional oxygen needed for

Metabolize lactic acid

- 80% of lactic acid produced by muscles enter bloodstream
- much of this lactic acid ends up in liver
- converted back to pyruvic acid in the kidneys, cardiac muscle, and especially the liver
- liver converts most of the pyruvic acid back to glucose to replenish the glycogen stored in the skeletal muscles or liver.
- This requires ATP and explains continued demand for oxygen even after strenuous exercise stops!

Serving the elevated metabolic rate

- occurs while the body temperature remains elevated by exercise and consumes more oxygen

Endurance

Endurance – the ability to maintain high-intensity exercise for more than 4 to 5 minutes

–determined in large part by one's maximum oxygen uptake (VO_2max)

–maximum oxygen uptake – the point at which the rate of oxygen consumption reaches a plateau and does not increase further with an added workload

•proportional to body size

•peaks at around age 20

•usually greater in males than females

•<u>can be twice as great in trained endurance athletes as in untrained person</u>

•May result in twice the ATP production

Muscle Fatigue

Characterized by progressive weakness and loss of contractility from prolonged use of the muscles

To experience muscle fatigue try this:

Repeated squeezing of rubber ball

Rapidly opening and closing your hand as if making a fist (one minute)

Holding textbook out level to the floor

Fatigue

Causes of muscle fatigue

–ATP synthesis declines as glycogen is consumed

–ATP shortage slows down the Na^+ - K^+ pumps

–Compromises their ability to maintain the resting membrane potential and excitability of the muscle fibers

–Lactic acid lowers pH of sarcoplasm

–Inhibits enzymes involved in contraction, ATP synthesis, and other aspects of muscle function

Fatigue

Causes of muscle fatigue (cont)

–release of K^+ with each action potential causes the accumulation of extracellular K^+ /// hyperpolarizes the cell and makes the muscle fiber less excitable

–motor nerve fibers use up their Ach /// less capable of stimulating muscle fibers – junctional fatigue

–central nervous system, where all motor commands originate, fatigues by unknown processes, so there is less signal output to the skeletal muscles

Beating Muscle Fatigue

Taking **oral creatine** increases level of creatine phosphate in muscle tissue and increases speed of ATP regeneration

useful in burst type exercises – weight-lifting

risks are not well known

muscle cramping, electrolyte imbalances, dehydration, water retention, stroke

kidney disease from overloading kidney with metabolite creatinine

Beating Muscle Fatigue

carbohydrate loading – a form of dietary regimen

Loads maximum amount of glycogen into muscle cells

extra glycogen is hydrophilic and adds 2.7 g water

athletes feel sense of heaviness outweighs benefits of extra available glycogen