ENERGY: FUEL SOURCES FOR THE WORKING MUSCLE

GATORADE SPORTS SCIENCE INSTITUTE

OVERVIEW

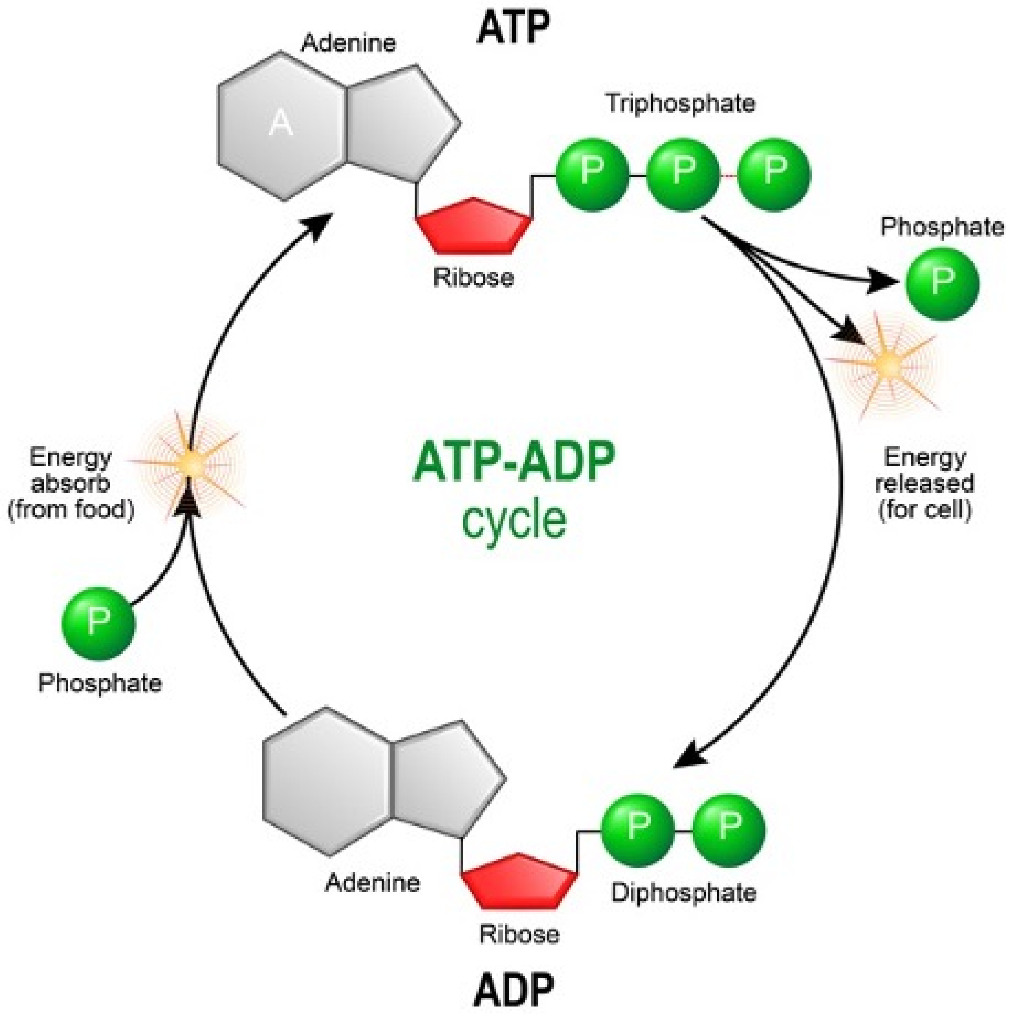
- Fuel Sources
- Energy Storage
- Energy Systems
- Review

ADENOSINE TRIPHOSPHATE (ATP)

Splitting a phosphate group from ATP supplies the energy for muscle contraction.

ATP is reformed from ADP with a phosphate from phosphocreatine (PCr).

Macronutrients from food are the fuel sources metabolized to generate ATP.



Hargreaves, M & Spriet, L. *Nat Metab*. 2020; https://doi.org/10.1038/s42255-020-0251-4.

ADENOSINE TRIPHOSPHATE (ATP)

Fuel Sources
metabolized to produce ATP:

Carbohydrate

Fat

Protein

CARBOHYDRATE

Energy: 4 kcal/g

Exists in the body as glucose.

Blood glucose provides energy for the brain and tissues.

Glycogen = storage form of glucose in the muscle and liver.

FAT

Energy: 9 kcal/g

High energy yield but ATP production process is slower than that of carbohydrates.

PROTEIN

Energy: 4 kcal/gram

While the amino acids from protein play a big role in the structure of various components of the body (muscle, hormones, etc.), their role for energy production is limited.

Amino acid oxidation for fuel mostly occurs only when other fuel sources are not available

PHOSPHOCREATINE (PCR)

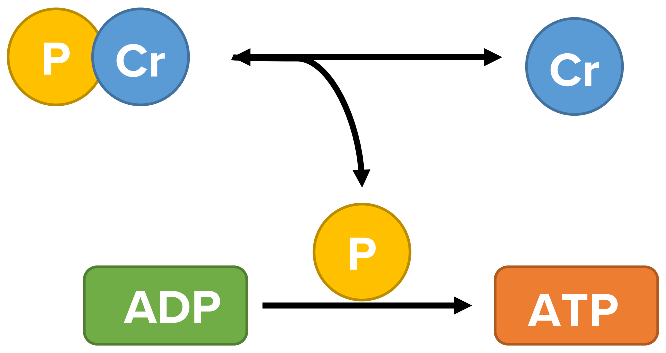
Phosphocreatine (PCr) is primarily found in the muscle, the phosphate group (P) is used to generate ATP from ADP

Used for very short duration (~5 s or less) high intensity muscle contraction

Creatine is produced in the body (~1-2 g/d)

Meats, particularly red meat, and fish such as salmon and tuna are rich in creatine

Creatine can also be consumed from supplements



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A NOTE ON MICRONUTRIENTS

Many micronutrients are involved in energy-producing processes.

Examples:

Iron helps deliver oxygen to the muscle for aerobic metabolism

B Vitamins are cofactors in the aerobic metabolism process

Vitamins and Minerals **do not provide energy** themselves, but they are critical to enable the energy-producing processes.

A NOTE ON CAFFEINE

Caffeine provides “energy” primarily by acting on the nervous system and binds to receptors in the brain to alter the release of neurotransmitters.

Caffeine does have ergogenic benefits for exercise performance, but it is not an energy source to provide fuel for muscle contraction.

Hargreaves, M & Spriet, L. *Nat Metab*. 2020; https://doi.org/10.1038/s42255-020-0251-4.

FUEL SOURCES MYTHS

- Nuts are an excellent source of quick energy
- All types of carbohydrate should be avoided
- B-vitamin supplements will provide a quick boost of energy before a workout
- Low carbohydrate, high protein and/or high fat diets provide the energy needed to improve performance

FUEL STORAGE

Hargreaves, M & Spriet, L. *Nat Metab.* 2020; https://doi.org/10.1038/s42255-020-0251-4.
van Loon LJ. *Appl Physiol.* 2004;97(4):1170-1187 https://doi.org/10.1152/japplphysiol.00368.2004.

GLUCOSE STORAGE

Glycogenesis = process of converting glucose into glycogen

Glycogen can be stored in the liver and the muscle in limited capacity

Muscle glycogen (~460-520 g) – only used by the muscle for energy.

Liver glycogen (~80 g) – can leave the liver as blood glucose to be used by the brain and other tissues.

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van Loon LJ. *Appl Physiol*. 2004;97(4):1170-1187 https://doi.org/10.1152/japplphysiol.00368.2004.

FAT STORAGE

Fat can be stored in several locations throughout the body including subcutaneous adipose, visceral adipose and muscle.

Intramuscular Triglycerides (IMTG) are a source of fuel for muscles to generate ATP, primarily during endurance exercise.

~200 g (1800 kcal) stored in the muscle.

The breakdown of IMTG provides free fatty acids for oxidation during low and moderate intensity exercise, sprinting and resistance exercise.

van Loon LJ. *Appl Physiol.* 2004;97(4):1170-1187
Spriet L and Randell R. *Sports Science Exchange*. 2020;29(205):1-6

FAT STORAGE

Lipogenesis = process of converting excess glucose into triglycerides (fat)

This typically occurs once glycogen stores are full and excess carbohydrate is consumed.

Fat can be stored in several locations throughout the body including subcutaneous adipose, visceral adipose and muscle.

Hargreaves, M & Spriet, L. *Nat Metab*. 2020; https://doi.org/10.1038/s42255-020-0251-4.

Manipulating Fuel Stores with Exercise Training & Diet

An adaptation that occurs with exercise training, particularly endurance exercise training, is an improved capacity to store glycogen.

To fully take advantage of this adaptation, athletes must consume adequate carbohydrate.

ENERGY SYSTEMS

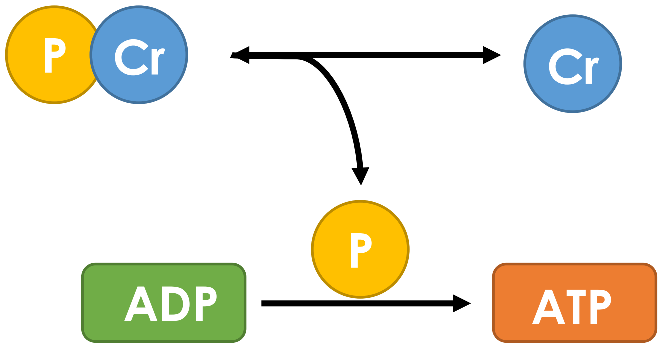
ATP-PCR

Utilized during <u>very</u> short duration, high intensity activities

Restores ATP stores after ATP depletion or during recovery

Allows for the constant replenishment of stored ATP

Does not require oxygen



ANAEROBIC GLYCOLYSIS

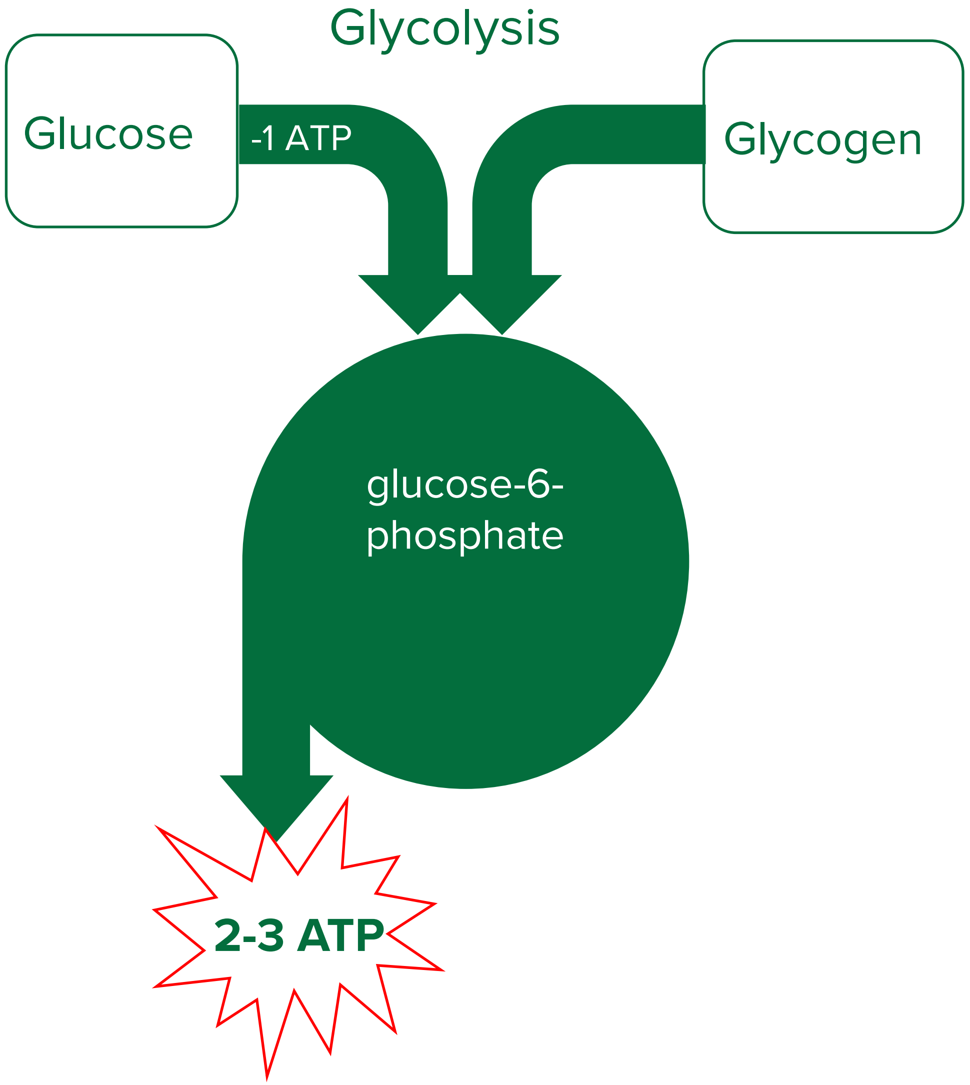
Utilized during short duration, high intensity activities

Glucose or glycogen converted into glucose-6-phosphate

2-3 ATP generated (2 for glucose, 3 for glycogen)

Anaerobic: does not require oxygen

By products: Lactate and Hydrogen Ion (H^+)



LIMITS TO ANAEROBIC ENERGY PRODUCTION

H^+ production reduces muscle pH

Improving the buffering capacity of the muscle to better handle the changes in pH helps promote anaerobic energy production.

Training: high-intensity interval training increases muscle buffering capacity and high-intensity exercise performance.

Nutrition:

- Bicarbonate loading can improve performance during exhaustive exercise lasting between 1 - 7 minutes. Gastrointestinal distress has limited the use of bicarbonate, but repeated doses over several days prior to competition may reduce the problems.
- Beta-alanine can improve muscle buffering capacity and high-intensity exercise performance.
- Creatine not only provides substrate to the ATP-PCr system but improves buffering capacity.

Sahlin K. *Sports Science Exchange.* 2017;28(171):1-4

OXIDATIVE SYSTEMS

Utilized during longer duration activities

Uses oxygen to generate energy from the breakdown of glucose/ glycoge and fat.

2 pathways based on substrate:

Carbohydrate Oxidation

Fat Oxidation

AEROBIC CARBOHYDRATE OXIDATION

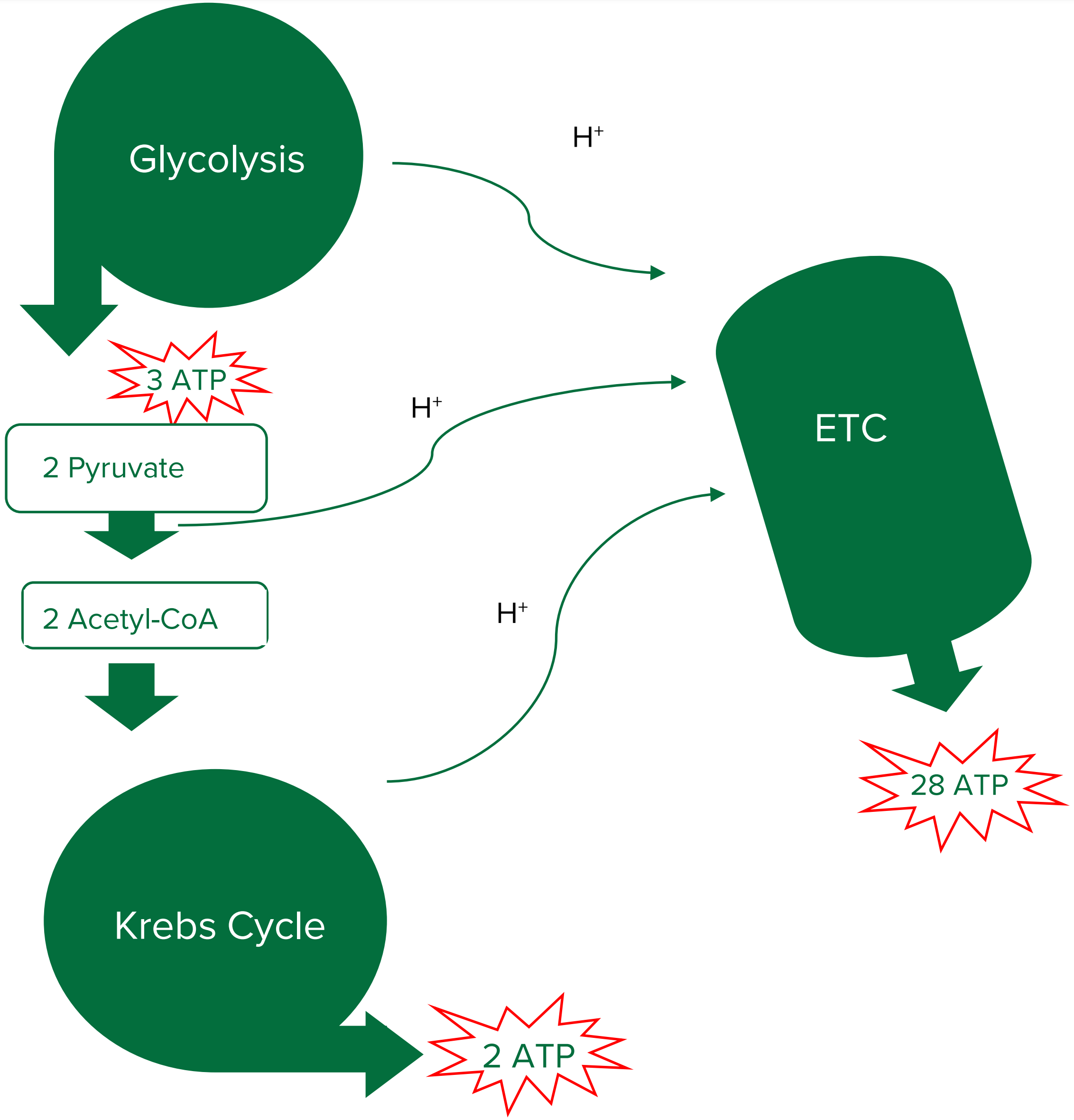
Glycolysis: **2-3 ATP** generated

Pyruvic Acid converted to Acetyl-CoA

Acetyl-CoA enters the Krebs cycle: **2 ATP** generated

H^+ ions are transported through the Electron Transport Chain (ETC): **28 ATP** generated

<u>32-33 ATP</u> generated in total for each Glucose/ Glycogen molecule



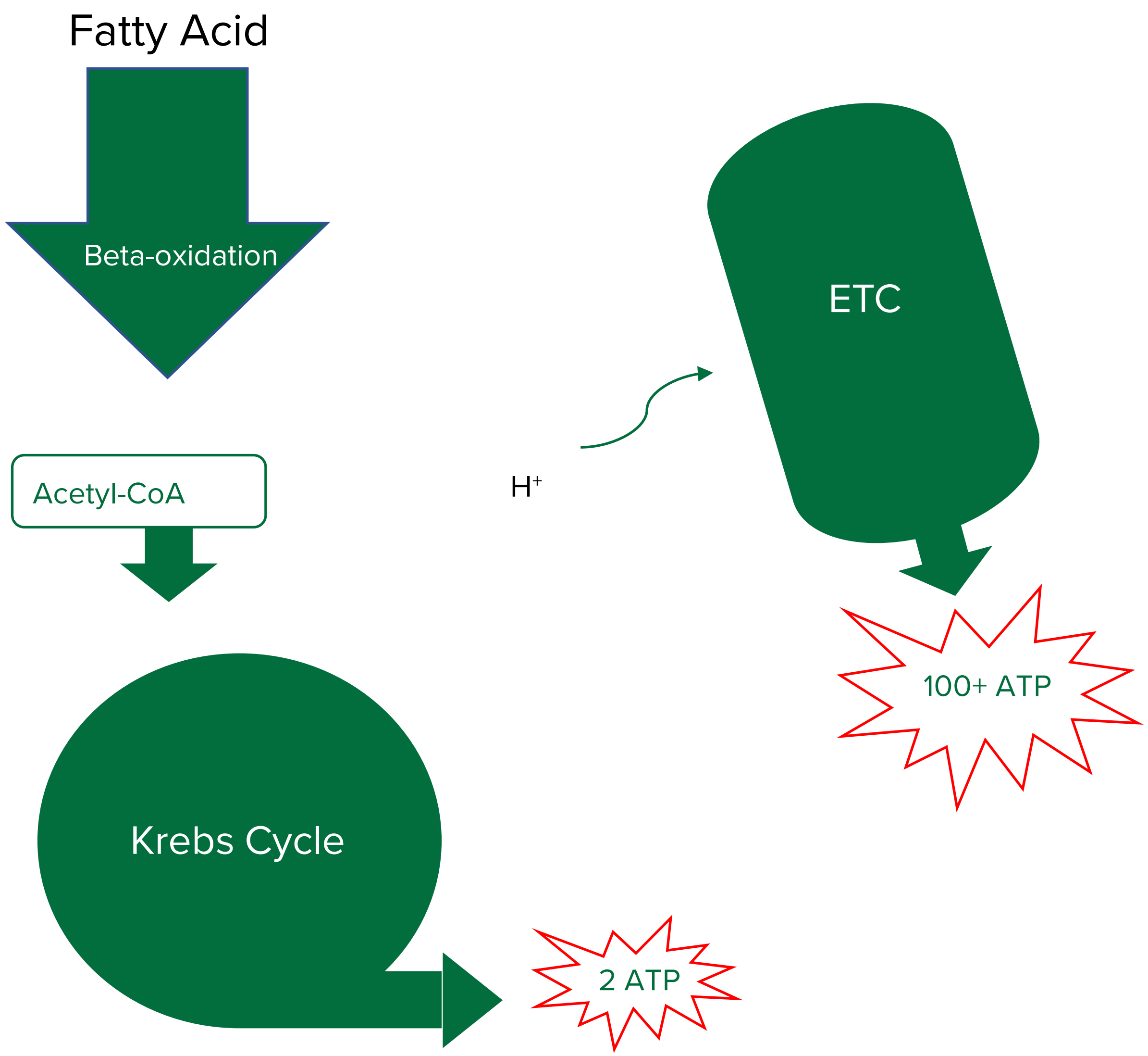
FAT OXIDATION

Fats follow a similar mechanistic path to carbohydrate with a few exceptions:

- Fat (triglyceride) stores are broken down to yield fatty acids through lipolysis.

- The fatty acids are converted into Acetyl-CoA through β-Oxidation.

The total energy yield will vary depending on the fatty acid however the ATP production will be very high (~100+), but the process is slower than carbohydrate.



PCR RESYNTHESIS

Interaction of Anaerobic and Aerobic Energy Systems

- The ability to rapidly resynthesize PCr is an important aspect of metabolism for stop-and-go sports
- Occurs when intensity falls to low levels or the athlete rests
- Continued aerobic production of ATP fuels regeneration of PCr
- PCR can be completely recovered in 60-120 s

LIMITS TO AEROBIC ENERGY PRODUCTION

The term “hitting the wall” often refers to glycogen depletion.

Enough fat is stored in the body, even in a lean individual, to provide energy. But ATP production from fat alone is too slow to sustain performance.

LACTATE

Historically, lactate was thought to be simply a waste product of aerobic metabolism and led to fatigue and muscle soreness.

It is now understood that the lactate produced from aerobic metabolism becomes an energy source itself for the heart, brain, kidneys and liver, and can be converted to glucose.

Brooks G. *Cell Metab.* 2018;27(4):757-785 https://doi.org/10.1016/j.cmet.2018.03.008

PROTEIN OXIDATION

Protein is not a primary fuel source.

Oxidation of amino acids contributes <5% of ATP synthesis.

Oxidation of branched chain amino acids may increase during endurance exercise; however, this seems to only be the case if sufficient carbohydrate is not ingested.

When they are used for energy, amino acids are converted to glucose through gluconeogenesis or converted to intermediates of the Krebs cycle.

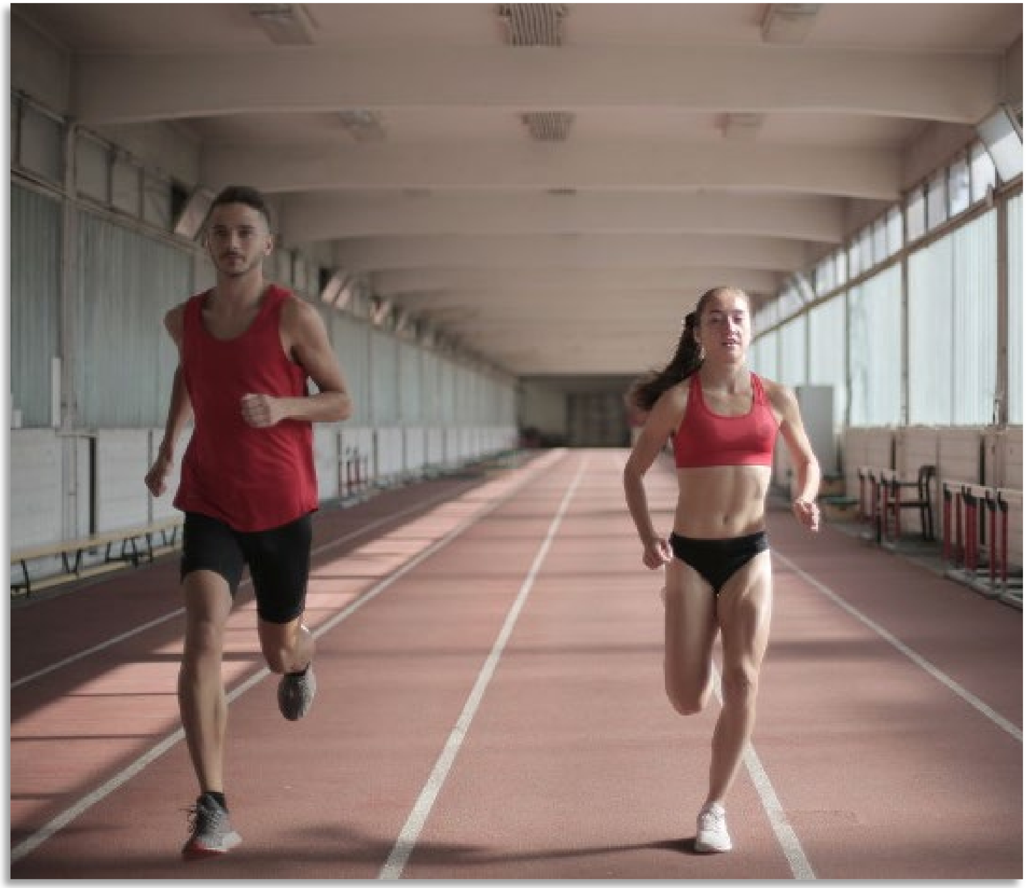
Hargreaves, M & Spriet, L. *Nat Metab*. 2020; https://doi.org/10.1038/s42255-020-0251-4.
Gibala MJ. *Sports Med*. 2007;37(4-5):337-40

SEX DIFFERENCES IN METABOLISM

At the same relative intensity, females use a larger percentage of fuel from fat.

Females have a lower maximal capacity of glycolytic enzymes and greater reliance on IMTG during exercise.

Likely related to estrogen levels.



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KEY TAKEAWAYS

- ✓ Macronutrients are oxidized to generate ATP, the energy source for muscle contraction
- ✓ Carbohydrate is stored in the muscle and liver as glycogen
- ✓ Fat is stored in adipose tissue and muscle (IMTG). Fat oxidation results in high ATP production but is a slow processes
- ✓ The energy systems are ATP-PCr, anaerobic glycolysis and aerobic metabolism
- ✓ Carbohydrate and fat are the primary fuel sources; protein oxidation for energy is minimal

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