Module 3. The role of fat in a player's diet

Unit 3.1 Introduction to Fat

Fat is an essential component of a footballer's diet because it has several important roles in their body, among other, it is an important fuel for contracting muscle. The intake of fat facilitates the absorption of fat-soluble vitamins (Vitamin A, D, E and K) and it provides an essential structural component of cell membranes. Although fats are important, high fat foods are often energy dense (9 calories per gram); therefore, diets abundant in high fat foods are discouraged for footballers. Players should be educated on the role of fat in supporting health and performance and identifying appropriate dietary sources of this nutrient. To this end, Unit 1 will provide an introduction to fat and Unit 2 will discuss the role of fat for football performance.

DID YOU KNOW?
The term fats and lipids are often used interchangeably. The key difference between lipids and fats is that lipids are a broad group of biomolecules whereas fats are a type of lipid.

Types of lipids

Lipids are defined chemically as a group of organic molecules composed of carbon, hydrogen and oxygen that are insoluble in water. There are different types of lipids depending on their chemical structure and/or function and can be classified as (Jeukendrup and Gleeson 2018):

1. Simple lipids
    - Neutral fats (triacylglycerol) and waxes (beeswax)
2. Derived lipids
    - Fatty acids, Steroids and Hydrocarbons
3. Compound lipids
    - Phospholipids, Lipoproteins and Glycolipids

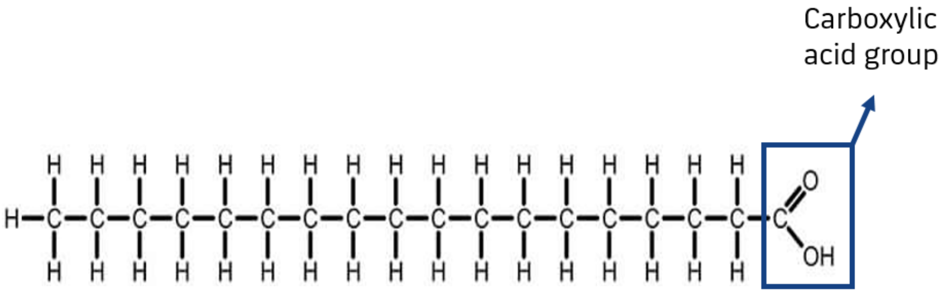
The different types of fats will be discussed in more detail with the aim of understanding their relevance in the diet and in the human body, as well as the importance for football players.

Fatty Acids

Fatty acids are classified as derived lipids. They are composed of a chain of carbon and hydrogen atoms with a carboxylic acid group at the end of the chain. The length of the carbon chain is important as it indicates the type of fatty acid. Typically, the length ranges from 4 to 24 carbon atoms. A fatty acid with a carbon chain of 6 or less is classified as short chain fatty acids (SCFAs), a chain of 8-10 carbon atoms is a medium chain fatty acid (MCFAs) and long chain fatty acids (LCFA) consist of >12 carbon atoms. The most abundant fatty acids are LCFAs.

Fatty acids can also be classified according to the number of double bonds that join the carbon atoms together. A saturated fatty acid contains no double bonds (Figure 1). Fatty acids with one double bond are classified as monounsaturated fatty acid (MUFA), and if two or more double bonds are present, it is called polyunsaturated fatty acid (PUFA) (Figure 2 & 3).

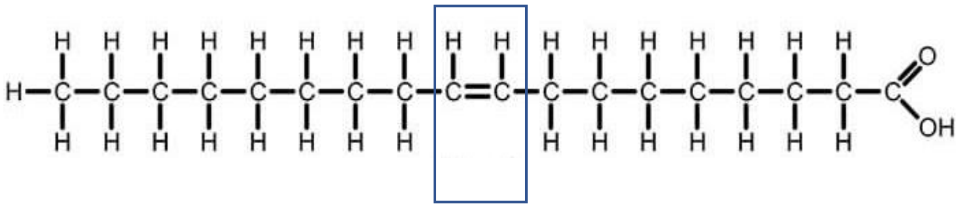
Figure 1: Saturated Fatty Acid



Saturated fatty acid (no double bonds)

Source: adapted from "Triglycerides Unsaturated Fat", n.d., https://bit.ly/2CtV0Ne

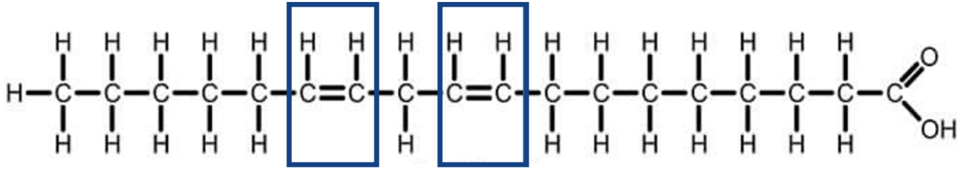
Figure 2: Monounsaturated Fatty Acid



Monounsaturated Fatty Acid (one double bond)

Source: adapted from "Triglycerides Unsaturated Fat", n.d., https://bit.ly/2CtV0Ne

Figure 3: Polyunsaturated Fatty Acid

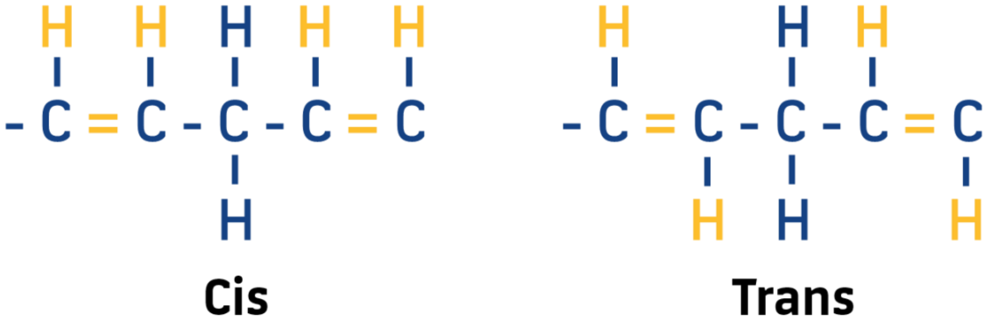


Polyunsaturated fatty acid (two double bonds)

Source: adapted from "Triglycerides Unsaturated Fat", n.d., https://bit.ly/2CtV0Ne

The arrangement of the hydrogen atoms around the double bonds (as shown in Figure 2 and 3) is known as a *cis* configuration (Figure 4). Most naturally occurring fatty acids adopt the *cis* configuration. Fatty acids that have a *trans* configuration are called *trans* fatty acids (Figure 4). Dietary *trans* fat are not essential and in fact consumption of *trans* fatty acids have been associated with a higher risk of cardiovascular disease (Mozaffarian, Katan et al. 2006).

Figure 4: *Cis* and *trans* configuration of fatty acids



Source: adapted from "Partially Hydrogenated Unsaturated Fat", n.d., https://bit.ly/2RRapkL

DID YOU KNOW?
Fatty acids can be classified depending on the number of carbon atoms and the absence or presence of double bonds. Most mono- and poly- unsaturated fatty acids adopt the cis formation.

Each fatty acid has a common name (see Table 1), but they can also be described with numbers. The numbers state the carbon atom chain length, and the number and position of double bonds. For example, the fatty acid 18:1 is Oleic Acid, it has an 18 carbon atom chain and 1 double bond; it is therefore a MUFA. This nomenclature can be extended to describe the location of the first double bond. For example, the fatty acid 18:2 *(n-6)* is Linolenic Acid, it has 18 carbon atoms and 2 double bonds; the first double bond is located at the 6th carbon atom. Table 1 shows an overview of some of the different fatty acids and their nomenclature.

Table 1: Different fatty acids and their nomenclature

Saturated fatty acids			
Number of carbon atoms and double bonds	Starting position of double bond	Common name	Found in
12:0	-	Lauric acid	Coconut Oil, Palm Kernel Oil
14:0	-	Myristic acid	Cow's Milk and Dairy products
16:0	-	Palmitic acid	Palm oil, meats, egg yolk
18:0	-	Stearic acid	Meat and cocoa butter
Unsaturated fatty acids			
Number of carbon atoms and double bonds	Starting position of double bond	Fatty acid name	Found in
18:2	n - 6	Linoleic acid	Olive oil
18:3	n - 3	**α**-Linolenic acid (ALA)	Flax seeds, walnuts
18:3	n - 6	**γ**-Linolenic acid	Hemp seeds, spirulina
18:4	n - 3	Stearidonic acid	Hemp seed oil
20:5	n - 3	Eicosapentaenoic acid (EPA)	Oily fish (salmon, mackerel)
22:6	n - 3	Docosahexaenoic acid (DHA)	Fish oil

Source: Prepared by author.

Like essential amino acids, there are some fatty acids that cannot be made (synthesized) in the body, they must therefore be incorporated into the footballer's diet. Linolenic acid and α-linolenic acid (ALA) are known collectively as *essential fatty acids* and can be found in foods such as flax seeds, hemp, walnuts and spirulina. These two fatty acids are also important because linolenic acid is an Omega-6 fatty acid and ALA is an Omega-3 fatty acid. Both Omega-3 and Omega-6 fatty acids are important components of cell membranes. Also, Omega-3 fatty acids have been found to exert many health benefits on cardiovascular disease, diabetes, cancer, depression and various mental illnesses (Shahidi and Ambigaipalan 2018).

In addition to ALA, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are the main long-chain Omega-3 fatty acids. Both EPA and DHA can be produced in the body when ALA is eaten in the diet. However, it is also recommended to eat foods rich in EPA and DHA. This can be achieved by eating oily fish, white fish, vegetable oils, nuts, soya and soya products and green leafy vegetables, among others. Regarding the quantity, there are no specific recommendations for Omega-3 dose for the general population or footballers. However, it is generally recommended to eat two portions of fish (~140 g per portion) per week, one of which should be oily fish. See Table 2 for an overview of dietary sources of omega 3 and 6.

Table 2: Dietary sources of omega-3 fatty acids

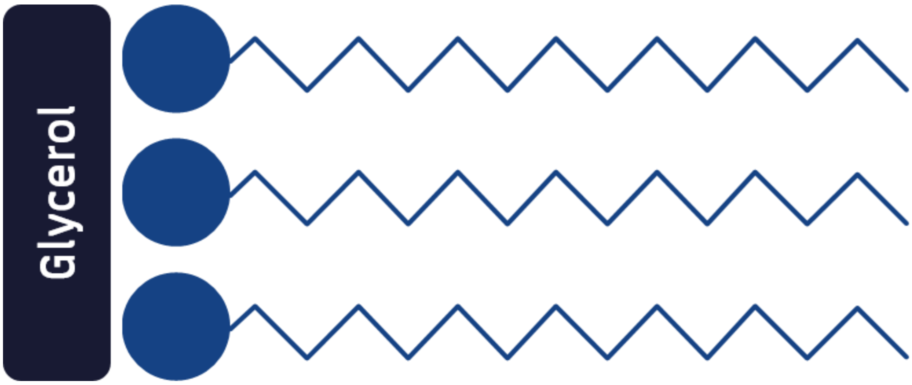
	High in Omega-3 fatty acids	High in Omega-6 fatty acids
Dietary Sources	• Fish (Mackerel, Salmon, Seabass, Oysters, Sardines) • Seaweed and algae • Chia seeds • Hemp seeds • Flaxseeds • Walnuts • Beans (edamame, kidney) • Green leafy vegetables	• Vegetable and seed oils: corn oil, sunflower oil, grapeseed oil, cottonseed oil (and anything cooked in these oils) • Nuts: walnuts, pistachios, cashews • Sunflower seeds, pumpkin seeds • Peanut butter • Fatty meats

Source: Prepared by author.

Triacylglycerols

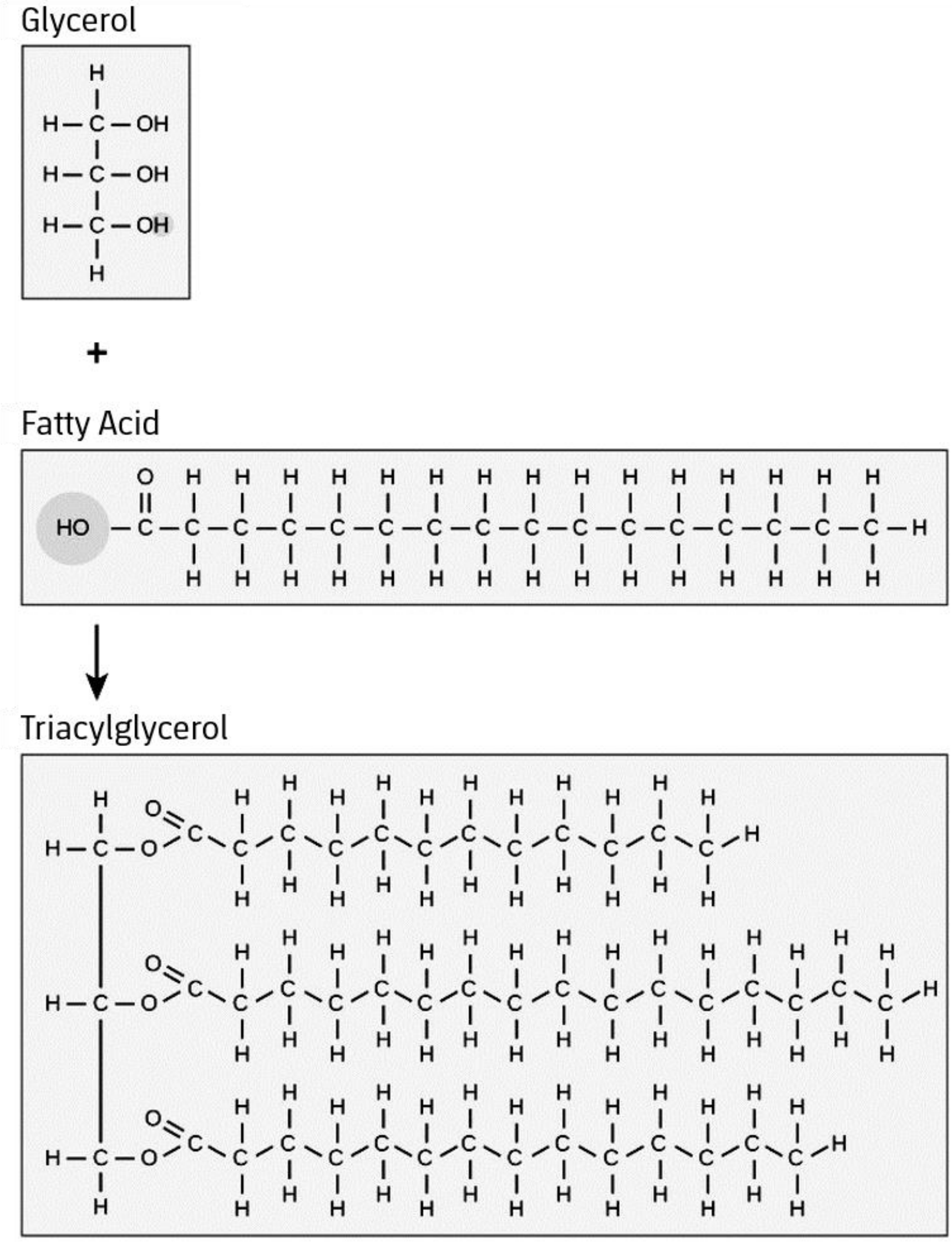
Triacylglycerols (TAGs) are simple lipids made from the combination of a glycerol backbone plus three fatty acids. When glycerol is bound to a single fatty acid, it is called monoacylglycerol (MAG), and when attached to two fatty acids, it is called diacylglycerol (DAG). However, the most abundant (95%) dietary fats consumed are TAGs; dietary MAGs and DAGs are also consumed, but in smaller amounts. A simplified and detailed structure of a TAG can be found in Figure 5 and 6; fatty acids that form TAGs can be saturated, unsaturated or a combination of both.

Figure 5: Cartoon Triacylglycerol Molecule



Source: prepared by author.

Figure 6: Formation of triacylglycerol



Source: "Lipids", n.d., https://bit.ly/2Dnvk6C

DID YOU KNOW?
Triacylglycerols are also referred to as triglycerides and they are often abbreviated to TAG or TGs. For this unit, the word triacylglycerol and the abbreviation TAG will be used.

Lipoproteins

Due to the insoluble nature of TAGs, they need to be transported around the body by lipoproteins. Lipoproteins are made up of TAGs, proteins, free cholesterol and phospholipids (Figure 7):

- TAGs: see section above for description.
- Apolipoprotein: the protein portion of any lipoprotein is called the apolipoprotein and each lipoprotein contains one or more apoprotein.
- Phospholipids: major components of lipoprotein cell membrane.
- Cholesterol: a lipid.

Lipoproteins differ depending on their density and triacylglycerol/cholesterol content and are classified as:

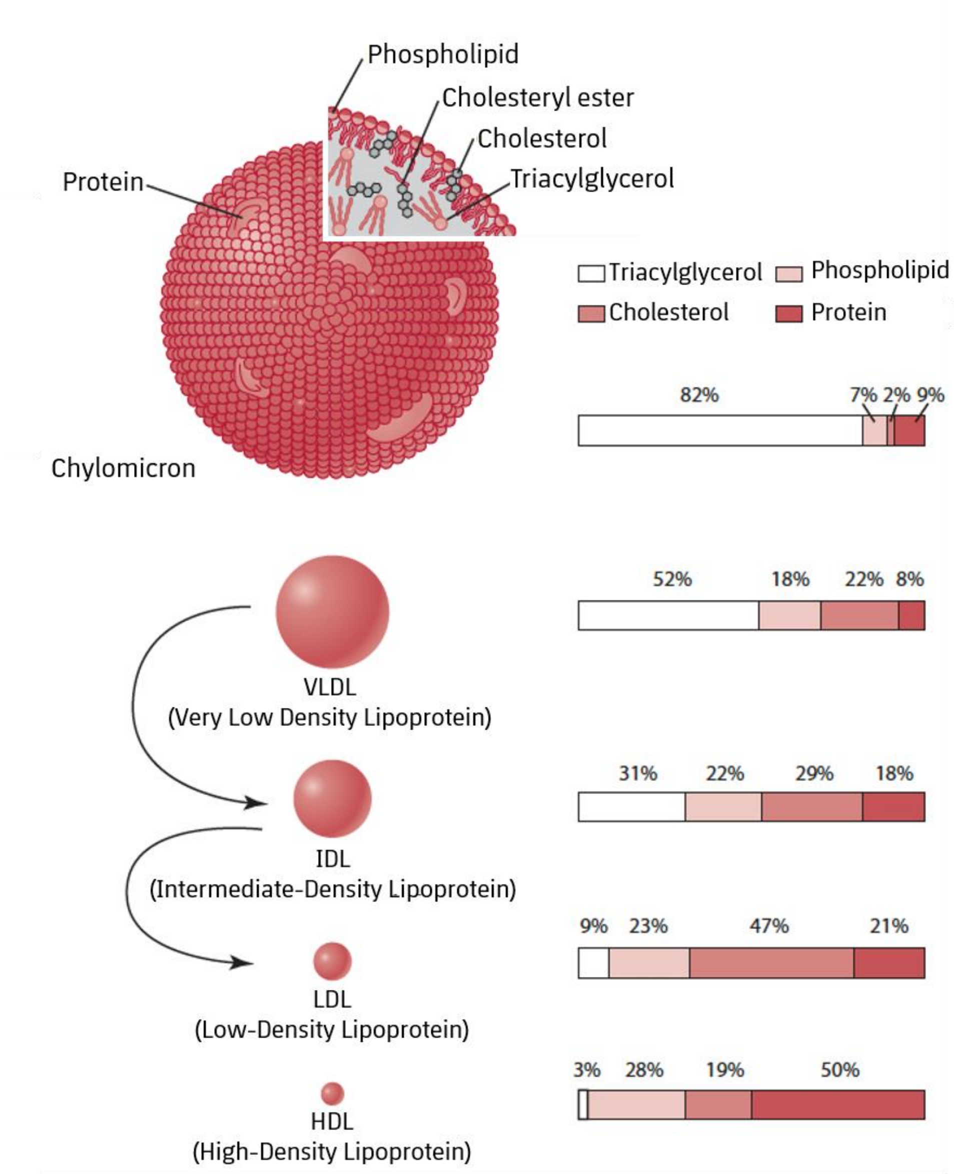
- Chylomicrons
- Very Low-Density Lipoproteins (VLDL)
- Intermediate-Density Lipoproteins (IDL)
- Low-Density Lipoproteins (LDL)
- High-Density Lipoproteins (HDL)

Each lipoprotein has a unique function. Chylomicrons transport lipids (TAGs and cholesterol) which have been consumed (exogenous) by other tissues, such as the muscle and adipose tissue, where the TAGs are removed and either stored or used for fuel. The cholesterol rich remnants of the lipoproteins are transported to the liver. This process is often referred to as the *exogenous* pathway (Walker, Hall et al. 1990).

The cholesterol and TAGs that reside in the liver are packaged into VLDLs and are released into the circulation. The VLDLs are transported to the adipose tissue and muscle where TAGs are once again removed, leaving cholesterol rich IDL. IDLs are either taken back up into the liver or they remain in the circulation as LDL. LDLs are known as the “bad” lipoproteins and high levels in the circulation increase the risk of coronary heart disease (Griffin, Freeman et al. 1994). As this process involved lipids that are already in the body, it is sometimes referred to as an *endogenous* pathway (Walker, Hall et al. 1990).

HDLs have a different function altogether: they are responsible for taking cholesterol from the tissues and the circulation to the liver, where the cholesterol is removed. HDLs are known as the “good” lipoproteins, and they have been found to reduce the risk of coronary heart disease (Gordon, Castelli et al. 1977).

Figure 7: Lipoprotein Structure and Content



Source: Gropper, Smith et al. (2016), p. 145.

Dietary sources

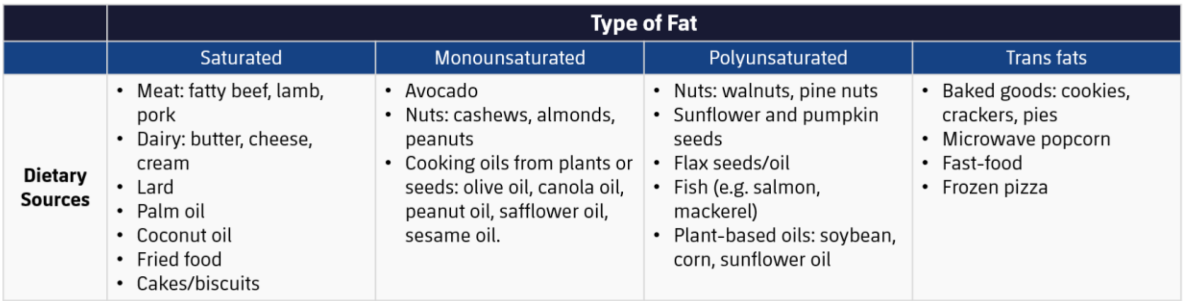
The Food and Agriculture Organisation (FAO) and the World Health Organisation (WHO) suggest that daily fat intake should not exceed 30%-35% of total energy intake. Data collected from 24 European countries found total fat intake to range from 29 – 46% of total energy intake, with Portugal and Greece as the lowest and highest, respectively (Eilander, Harika et al. 2015).

However, the type of dietary fat consumed is of huge importance. The FAO/WHO recommend that saturated fatty acids should not exceed 10% of total energy intake. High levels of saturated fats are found in red meat, butter and cheese. As mentioned above, there is convincing evidence that polyunsaturated fats decrease the risk of chronic heart disease; therefore saturated fatty acids should be replaced with polyunsaturated fatty acids in the diet. Foods high in polyunsaturated fatty acids include nuts, oily fish and some seeds.

Trans fats (fatty acids with a *trans* configuration) are not an essential part of the human diet. In fact, *trans* fatty acids have been found to increase LDL lipoproteins and decrease HDL, which in turn increases the risk of cardiovascular disease (Brouwer, Wanders et al. 2010, Brouwer, Wanders et al. 2013). High quantities of *trans* fats are often found in energy-dense, processed and fried foods. The UK Scientific Advisory Committee on Nutrition recommends that the intake of *trans* fat should not exceed>2% of total energy intake.

Taking this information together, a practitioner working in elite football should consider the type of dietary fats they recommend to the players. A comprehensive table of dietary fat sources can be found in Table 3.

Table 3: Dietary sources of different types of fat



	Type of Fat			
	Saturated	Monounsaturated	Polyunsaturated	Trans fats
Dietary Sources	• Meat: fatty beef, lamb, pork • Dairy: butter, cheese, cream • Lard • Palm oil • Coconut oil • Fried food • Cakes/biscuits	• Avocado • Nuts: cashews, almonds, peanuts • Cooking oils from plants or seeds: olive oil, canola oil, peanut oil, safflower oil, sesame oil.	• Nuts: walnuts, pine nuts • Sunflower and pumpkin seeds • Flax seeds/oil • Fish (e.g. salmon, mackerel) • Plant-based oils: soybean, corn, sunflower oil	• Baked goods: cookies, crackers, pies • Microwave popcorn • Fast-food • Frozen pizza

Source: prepared by author.

Fat digestion and absorption

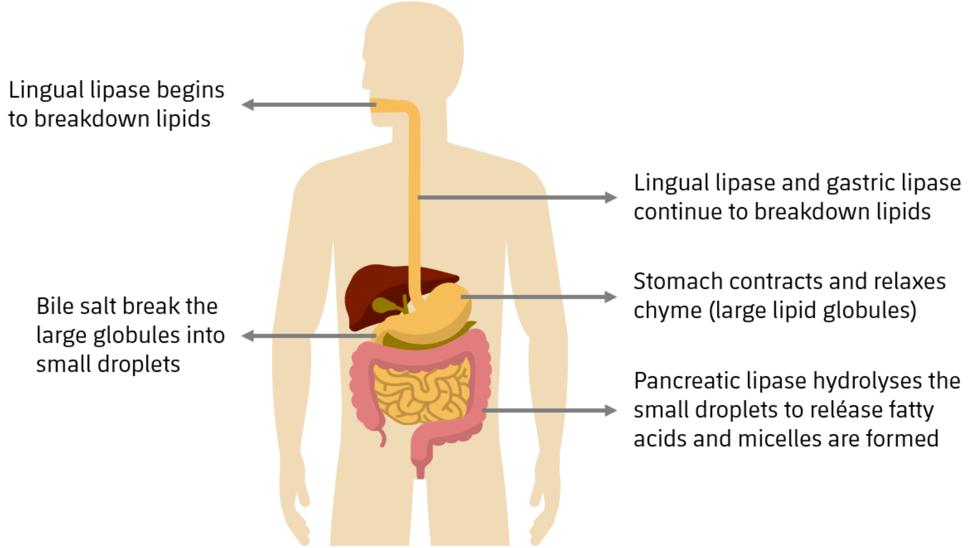
Most (~90%) dietary lipids consumed by humans are in the form of TAGs; however, dietary lipids also comprise MAGs, DAGs, cholesterol, and phospholipids. Due to the insoluble nature of lipids, many enzymes are involved in breaking down (emulsification) lipids so that they can be digested and absorbed.

The first step starts in the mouth, where the enzyme lingual lipase works to breakdown (hydrolyse) the lipids. Once in the stomach, both lingual and gastric lipases work together to break down fatty acids. However, these enzymes only work on MCFA and SCFA; therefore, a relatively small amount of digestion takes place in the stomach because the majority of lipids consumed are LCFA. Another function of the stomach is to relax and contract, which mixes the contents to produce chyme. Thus, if a meal high in fat has been consumed, the chyme will be predominately made up of large lipids globules, containing TAGs, MAGs, DAGs, fatty acids, cholesterol, etc.

These large globules of lipids are poorly absorbed by the intestines; therefore, as the chyme enters the small intestine's bile salt (an emulsifier), it is secreted to break down the globules into smaller droplets. The larger surface area of the small droplets facilitates the enzyme pancreatic lipase to further hydrolyse the lipids into fatty acids. The bile salts attach to the fatty acids and phospholipids to form micelles. These micelles are a key part of the digestion process because they are responsible for transporting the poorly soluble fatty acids to the cell membrane of the epithelial cells (the cells on the border of small intestines), where they can be absorbed. See Figure 8 for a simplified overview of fat digestion.

Once at the cell membrane, the role of the micelles is complete, and the fatty acids diffuse into the epithelial cell. Inside the cell, the LCFAs are reformed (esterification) into TAGs and combined with apolipoproteins, phospholipids and cholesterol to form chylomicrons. Chylomicrons enter the lymphatic capillaries, which transport them to the venous circulation, to be taken up by various tissues. On the other hand, SCFA and MCFA are not re-esterified into TAGs —they directly diffuse into plasma, where they bind with the protein albumin and are transported to the liver.

Figure 8: Fat Digestion



Source: Prepared by author.

Storage of fat in the human body

The major fat store in the body is subcutaneous adipose tissue, that is, a layer of fat located below the skin. In humans, white adipocytes (fat cells) make up the majority of the adipose tissue; however, brown adipose cells are also present. These two types of adipocytes play several critical roles in the systemic metabolism and physiology. The main role of white adipocytes is to store energy in the form of TAGs, and to release fatty acids for fuel when needed. In contrast, brown adipocytes are specialized to dissipate chemical energy in the form of heat. For a typical 80 kg male, with a body fat percentage of 15%, ~12 kg of fat will be stored as adipose tissue. Although football players typically have a lower body fat percentage, the majority of their fat will still be stored as adipose tissue.

TAGs can also be stored inside skeletal muscle –within the muscle fibres–, and are known as intramuscular triacyglycerides (IMTGs). However, the lipid storage capacity of skeletal muscle is much lower than that of adipose tissue. Skeletal muscle contains on average about 12 mmol/kg ww IMTG (~0.3 kg of IMTG in an 80 kg male), although this can vary depending on factors such as fibre type, nutrition and physical exercise. Type I fibres contain more IMTGs than type IIa fibres, with type IIb fibres displaying the lowest concentrations. IMTGs stored in muscle are an important source of energy for muscle during rest as well as in exercise conditions, and it has been shown that trained subjects have more IMTGs than non-trained individuals (Jeukendrup, Saris et al. 1998).

Synthesis and storage process

As outlined above, after a meal has been digested, lipids are packaged into chylomicrons and are released into the circulation (*exogenous pathway*). Alternatively, the liver secretes lipids into the circulation in the form of VLDLs (*endogenous pathway*). The fatty acids in chylomicrons and VLDLs are released from their TAGs by an enzyme known as lipoprotein lipase (LPL). LPL is synthesized by adipose and skeletal muscle tissue, secreted from the cell, and attached to the endothelial lining of a nearby capillary (Tiidus, Houston et al. 1995), which liberates the fatty acids. Following a series of events (outlined in more detail in the lipolysis section below), the fatty acids are taken up by the tissue.

In humans, excess dietary intake of carbohydrate and fat-rich foods, over and above what is needed for fuel, leads to increased storage of fat. Most of this fat storage is a result of increased dietary fat intake, not the conversion of dietary carbohydrate into fatty acids in fat cells (Flatt 1995). In addition, high dietary carbohydrate intake will result in an increase in carbohydrate oxidation (in muscle and other tissues) and a reduction in fat oxidation. This results in more dietary fatty acids available for storage, and explains why excess dietary fatty acids are preferentially used for increased triacylglycerol synthesis and excess carbohydrates are preferentially oxidized. An exception for this is dietary fructose, which is primarily converted to fatty acids in the liver, promoting fat storage (Tiidus, Houston et al. 1995).

Fatty acids breakdown, uptake and oxidation

Lipolysis is the process by which TAGs in the muscle cells and adipose tissue are broken down to glycerol and fatty acids. Lipolysis occurs during exercise as well as in fasting conditions, when fatty acids are needed as an energy source by various tissues. On the contrary, lipolysis is supressed within a few hours (1–2 hours) after a meal; particularly, if the meal is high in carbohydrates. This process is controlled by hormones such as insulin and catecholamines.

Since triacylglycerides are made of three fatty acids, lipolysis requires the activation of specific enzymes to remove each of the fatty acids from the glycerol backbone. In the adipose tissue, the enzyme adipose triglyceride lipase (ATGL), hormone sensitive lipase (HSL) and monoacylglycerol lipase (MGL) remove the three fatty acids sequentially.

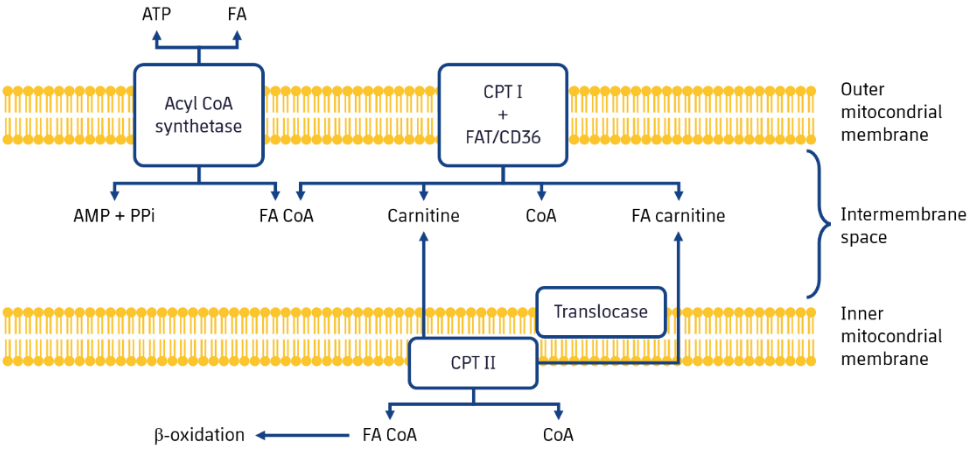
Once fatty acids and glycerol are released by adipose tissue as a result of lipolysis, they pass out of the adipocyte into the blood. Glycerol is soluble, but the fatty acids are bound to albumin molecules in blood. Albumin molecules are proteins and they have the capacity to carry up to ten fatty acid molecules. In order to be oxidized for fuel, fatty acids must reach the mitochondria in the skeletal muscle. To this end, the amount of fatty acids delivered to muscle from adipose tissue depends on the blood flow through the adipose tissue and on the number of albumin molecules in the blood.

Once in the muscle proximity, various transporters are responsible for the shuttling of fatty acids across the cell membrane, these are: FA binding protein (FABPpm) (41); FA translocase CD36 (FAT/CD36) (12), and FA transport protein (FATP). FABPpm is located on the membrane of the muscle cell, whereas FAT/CD36 is primarily located inside the muscle and translocates to the membrane when needed. All fatty acid transporters are induced by diet and exercise. For example, exercise training —especially endurance training-— will increase the amount of fatty acid transporters, potentially increasing the uptake into the muscle (Kiens 1997). Likewise, a diet high in fat and low in carbohydrate over an extended period of time also leads to more fatty acid transporters being produced (Yeo, Carey et al. 2011).

IMTGs are another source of fatty acids that can be oxidised for fuel. Like adipose tissue, the breakdown of IMTGs is also controlled by hormones, such as insulin and catecholamines, and HSL is required to remove fatty acids from the glycerol backbone. Fatty acids in the cytoplasm of skeletal muscle, either from adipocytes or from IMTGs, must be transported into the mitochondria to be oxidised and used as fuel.

A series of processes are required to uptake fatty acids into the mitochondria. Firstly, on the outer membrane of the mitochondria, fatty acids are activated by the enzyme Acetyl-CoA Synthase to form fatty acyl-coA. Carnitine is important in transporting the activated fatty acids (fatty acyl-CoA) into the mitochondria. Carnitine is bound to the fatty acyl-CoA by the enzyme Carnitine Palmitoyl Transferase (CPT1), forming acylcarnitine. CPT-1 transports the acylcarnitine molecule across the mitochondrial membrane to the inner surface, whereby Carnitine Palmitoyl Transferase 2 (CPT-2) removes the carnitine and leaves the activated fatty acid (fatty acyl-CoA) in the mitochondrial matrix. The free carnitine is translocated back to the outer membrane, where it can pick up another activated fatty acid. This is sometimes known as the carnitine shuttle (Figure 9). Remarkably, only long chain fatty acids are transported in this manner, as medium and short chain fatty acids are capable of passing directly through the mitochondrial membrane without a transporter. In addition, it has recently been discovered that FAT/CD36 is also involved in transporting fatty acids into the mitochondria for oxidation.

Figure 9: Carnitine Shuttle



Source: Tiidus, Houston et al. (1995)

Once inside the mitochondrial matrix the fatty acyl-CoA undergoes the β-oxidation process. Simply put, this process removes two acetyl-CoA molecules from the fatty acid chain (per cycle). These acetyl-CoA molecules are then used in the TCA cycle for the production of ATP.

Summary

- Fatty acids can be saturated, monounsaturated or polyunsaturated in nature, depending on the number of carbon double bonds in their structure.
- Fatty acids are transported around the body by specific proteins called lipoproteins.
- Dietary fat intake should not exceed 35% of total energy intake.
- The adipose tissue is the main site for fat storage.
- Bile salts and pancreatic lipase are the main contributors for fat digestion.
- Lypolysis in the adipose tissue and skeletal muscle provide fatty acids for oxidation.
- The end result of β-oxidation provides acetyl-CoA for the TCA cycle.

Disclaimer: Ian Rollo is an employee of the Gatorade Sports Science Institute, a division of PepsiCo, Inc. The views expressed in this course are those of the authors and do not necessarily reflect the position or policy of PepsiCo, Inc.

Unit 3.2 Fats for Football

Dietary fat is an important part of a player's habitual diet for the following reasons: it is 1) an energy source, 2) a vehicle for the intake and absorption of fat- soluble vitamins, and 3) a source of essential fatty acids. Depending on the situation, football players are advised to adjust the intake of fat to allow protein and carbohydrate requirements to be met within total energy targets. Players are also advised to follow general population guidelines to minimize the intake of trans fatty acids and heed caution with excessive intakes of saturated fats (Unit 1).

In general, players do not need to specially address their "fat intake", but simply make good choices surrounding the types of fat in their diet. In general, when players ingest a well-balanced diet, fat intake will naturally account for 15-20% of total dietary intake. Therefore, it is more important for players to focus on the type of fat that is ingested as there is emerging evidence that the ingestion of specific fats may be a benefit to a football player. However, it is important to note that some players may restrict fat intake to reduce total energy intake or because they think it is a "healthy" option. An excessive restriction of fat intake to <15-20% of energy often results in an unnecessary avoidance of a range of foods with otherwise valuable nutrient profiles. Finally, players are also exposed to misinformation about supplements for "fat burning", thus, this topic will also be discussed in this unit.

Fat utilisation during football

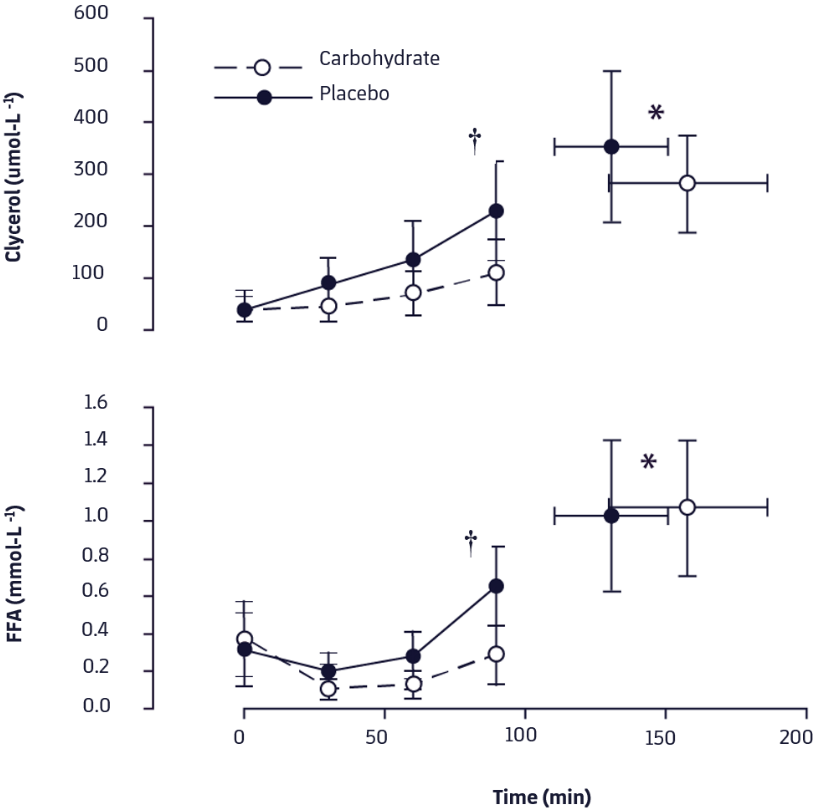
The intermittent running pattern of football allows periods of lower intensity activity, resulting in significant blood flow to adipose (fat stores) tissue, which promotes the release of free fatty acid (FFA). Therefore, over the course of a football match, there is a gradual increase in FFA concentrations in the player's blood (Bangsbo, 1994a). The high rate of lipolysis during a game is also supported by observations of elevated levels of glycerol (Bangsbo, 1994a).

In addition to an increase in blood flow to the adipose tissue, the progressive increase in FFA concentration is determined by key hormones. During exercise, concentrations of insulin are lowered and catecholamine levels are progressively elevated, promoting a high rate of release of FFA into the blood (Bangsbo, 1994b). The FFA and glycerol concentrations during a simulated football protocol (LIST), with and without carbohydrate feedings, are displayed in Figure 1. Please note that, although carbohydrate ingestion (90 g/h) reduced FFA concentrations (as expected), performance —measured via a run to fatigue— was improved with carbohydrate ingestion.

DID YOU KNOW

Lipolysis is the term given to the breakdown of stored fat to release fatty acids.

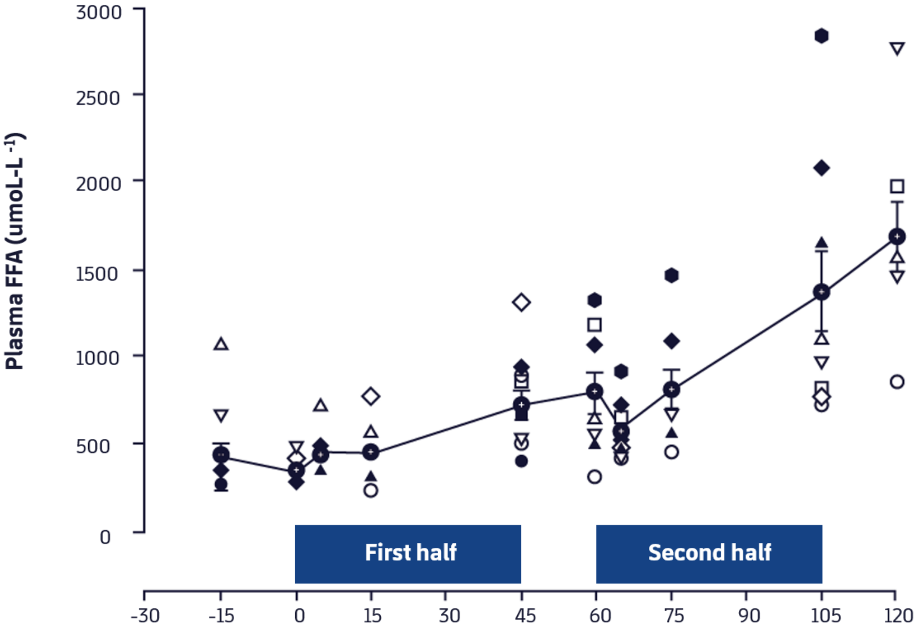
Figure 1: Free fatty acid and glycerol concentrations during the LIST protocol and at fatigue (P<0.003)



Source: (Foskett, Williams, Boobis, & Tsintzas, 2008).

Over a 90-minute match, there is an increase in FFA availability. Increasing fat use is likely a compensatory mechanism for the progressive lowering of muscle glycogen and it is used to maintain the blood glucose concentration during the match. Interestingly, in the first 20-minutes, a slight reduction in FFA in the circulation is observed. The reduction in FFA concentration following kick-off in the first and second half of a game (Figure 2) reflects higher uptake and use of FFA by contracting muscles.

Figure 2: Plasma FFA concentrations before, during, and after a football match. Data are means as well as individual values



Source: (Krustrup et al., 2006).

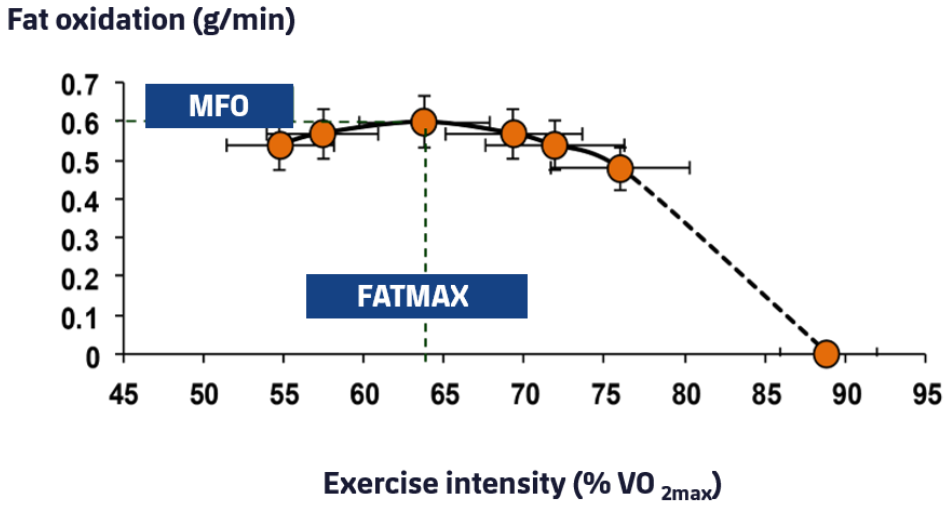
Fat oxidation in football

Exercise intensity is the most important factor influencing fat utilisation. At higher exercise intensities, fat use declines —despite increased energy requirements— and carbohydrate becomes the predominant fuel source. A single incremental exercise test (FATMAX test) can establish an individual player's fat oxidation rates over a wide range of exercise intensities and establish maximal fat oxidation rates (MFO). This test can also establish the exercise intensity at which the rate of fat oxidation is greatest (FATMAX). The player's FATMAX is expressed as a percentage of their maximal oxygen uptake or a percentage of maximal heart rate.

Team sport athletes who participate in rugby, American football, basketball and soccer display higher absolute MFO rates compared to sports such as golf, baseball and tennis (Randell et al., 2017). Importantly, studies utilising the FATMAX test have consistently reported significant individual variation in maximal rates of fat oxidation within each sporting sub-group. In football, fat oxidation rates ranged from 0.17 – 1.11 g/min in a group of 283 players that included recreational as well as professional players (Randell et al., 2017).

Fat oxidation during a match and/or training is of interest as higher rates of fat oxidation during periods of lower-intensity exercise may potentially preserve the bodies' limited supply of muscle glycogen (Module 1). The available literature would suggest that individual players will have significantly different capacities to use fat. Thus, understanding an individual player's fuel preference (carbohydrate or fat) at lower exercise intensities may allow more personalised nutrition recommendations for training and matches. However, further research is required before solid nutritional recommendations based on this information can be made for players. Interestingly, significant and positive associations have been reported between maximal rates of fat use during exercise and total fat use measured over 24 hours (Robinson, Hattersley, Frost, Chambers, & Wallis, 2015). Future research may provide more insight into the long-term implication of this relationship, which could be a first step towards specific "fat"-orientated nutrition strategies for players. The relationship between exercise intensity and fat use during exercise can be seen Figure 3. The FATMAX test can be performed on a treadmill or cycle ergometer.

Figure 3: Maximal fat oxidation (MFO) and intensity at which MFO is achieved (FATMAX)



Source: prepared by author.

High fat diets

There has been interest in sports nutrition in promoting low-carbohydrate, high-fat diets to enhance the capacity for skeletal muscle to use fat (Volek, Noakes, & Phinney, 2015). The low-carbohydrate (<25% energy intake), high-fat (>60% energy intake) diet restricts the ingestion of carbohydrate-based foods whilst encourages the consumption on high-fat foods. Daily fat ingestion is approximately 4 g/kg body mass (BM).

The concept of such a dietary practice is that players can increase the utilization of the abundant endogenous fat stores (> 30,000 kcal), and therefore, "spare" the limited storage of CHO sources (~2,000 kcal). Although anecdotal reports exist from some professional athletes who follow such a diet, currently, there is no observational or intervention research which would promote a low-carbohydrate, high-fat diet for football specific (repeated sprint) performance (Burke, 2015). However, the effects of a high-fat diet versus a carbohydrate rich diet while training have been investigated in endurance athletes. In this study, five days of high-fat intake (4.6 g/day) were followed by 1 day of a carbohydrate-rich diet (restoration: 10 g/kg) and rest (Stellingwerff et al., 2006). This study measured the regulation of key regulatory enzymes in the pathways of skeletal muscle fat and carbohydrate metabolism during sprint exercise (Stellingwerff et al., 2006). Resting pyruvate dehydrogenase activity was lower at rest and estimated rates of glycogenolysis were reduced upon the completion of a standardized 1 min sprint after fat-adaptation compared with a high carbohydrate diet. The results from this study suggest that muscle glycogen "sparing", as a result of increased fat use, may be due to an impairment of glycogenolysis (due to a down-regulation of pyruvate dehydrogenase). Thus, high-fat diets which promote such adaptation would not be considered as favourable to players who are required to perform repeated bouts of maximal sprint activity.

DID YOU KNOW?
Pyruvate dehydrogenase is a key enzyme required to turn the products of carbohydrate metabolism (glycolysis) into Acetyl-CoA, which can then proceed to aerobic metabolism.

Whole Foods

It is common for sports nutrition studies to investigate macronutrients in isolation. For example, in protein research, protein isolates (such as whey or casein) have been commonly investigated, rather than the "whole food", in this case, milk. Real foods contain a complex matrix of vitamins, minerals and other macronutrients, including fats. Thus, investigations into "whole foods" are more representative of a player's diet.

The first study to investigate whole foods in the context of recovery was performed by Elliot, Cree, Sanford, Wolfe, and Tipton, in 2006. In this study, participants ingested one of three milk drinks 1 hour after resistance exercise. The three drinks were all milk but differed in their fat content. One drink was fat-free milk, the second drink was whole milk and the third drink was fat-free milk but with added sugar so that it had the same energy content as the whole milk. It was found that the availability of amino acids for protein synthesis was higher following the ingestion of whole milk in comparison to the other drinks (Elliot, Cree, Sanford, Wolfe, & Tipton, 2006).

Similarly, the ingestion of whole eggs immediately after resistance exercise has been reported to result in greater stimulation of myofibrillar protein synthesis than did the ingestion of egg whites, despite being matched for protein content (van Vliet et al., 2017). Thus, there is emerging evidence the ingestion of nutrient- and protein-dense foods differentially stimulates muscle anabolism compared with protein-dense foods alone. Further research is required to fully understand this interaction and response. Nevertheless, with respect to module 2 (Protein) the inclusion of "non-protein" dietary factors, such as fats, may be important to influence the post-exercise adaptive response and recovery of the player's muscle (Abou Sawan et al., 2018).

Fat burners

A common category of nutrition supplements promoted in the media and on-line, and which the player is frequently exposed to, is 'fat burners'. The term 'fat burner' is used to describe nutrition supplements that are claimed to acutely increase fat metabolism or energy expenditure, impair fat absorption, increase weight loss, increase fat oxidation during exercise, or somehow cause long-term adaptations that promote fat metabolism (Jeukendrup & Randell, 2011). This category of supplementation often appeals to the players as a quick fix for improved health and performance, and advertisements are often accompanied by "aesthetically" driven marketing. Common "claims" include improvements in performance, weight loss, fat loss, muscle gain or a combination of these factors.

A full module will be dedicated to dietary supplementation in football in later courses. Ingredients which have been proposed to increase fat burning are listed in Figure 4. It is important to note that supplements often contain several of these ingredients, each with a different proposed mechanism of action. It is often claimed that the combination of a number of these substances will have additive effects. However, very few dietary supplements have appropriate evidence to support their use. The expansive list of fat-burning supplements is industry (profit) driven and it is likely to grow at a rate that cannot be matched by a similar increase in scientific underpinning. Thus, for most supplements claimed to be "fat burners", there is a lack of scientific data. Based on the available studies, caffeine and green tea have some evidence that they could, in some circumstances, enhance fat metabolism.

Figure 4: A list of available supplements that have been proposed to increase fat metabolism

Caffeine
Dihydroxyacetone
Conjugated linoleic acid (CLA)
Carnitine
Ephedra
Psyllium
Calcium
Green tea extracts
Pyruvate
Choline
Hydroxycitrate (HCA)
Leucine
Chromium
Lipase
Forskolin
Lecithin
Ma huang
Beta-sitosterol
Fucoxanthin
Kelp
Cayenne pepper (Capsaicin)
Garcinia
Cambogia
Inositol
Taurine
Tea

Source: (Jeukendrup & Randell, 2011)

Caffeine ingestion may increase energy expenditure (at rest) or fat oxidation (at rest and during low-intensity exercise), but these effects are less obvious during moderate- to high-intensity exercise. It is important to note that caffeine on its own has not been shown to be effective in reducing body weight (Jeukendrup & Randell, 2011). Therefore, the common consensus is that caffeine may exert a small effect on increasing fat metabolism and studies should be interpreted with caution (Jeukendrup & Randell, 2011).

On the whole, research has not found green tea supplementation to influence fat use during exercise (Randell et al., 2013). However, green tea ingestion may have the potential to increase fat metabolism at rest, and thus, may "help" to lose body fat and body weight. As with caffeine, the effects appear to be relatively small, and the underlying mechanisms for the metabolic effects of green tea ingestion are not fully understood. Therefore, the practical recommendations with regard to green tea ingestion are not clear for players (Jeukendrup & Randell, 2011).

Of note is that the impact of both caffeine and green tea on fat metabolism is minor in comparison to those factors (i.e. training status, exercise intensity, exercise duration, carbohydrate status) known to influence fat metabolism at rest and during exercise.

OMEGA-3

Players should avoid unfavourable lipid profiles (pro-inflammatory) to prevent excess trans-fat, saturated fat and excessive omega-6 fat, from vegetable oils, in the diet. Instead, players are encouraged to regularly eat foods rich in omega-3 (Simopoulos, 2007). Omega-3 has known health benefits and comes in three different forms as explained below.

Alpha-linolenic acid (ALA) cannot be synthesised by the players body so must be obtained by ingestion in the player's diet. The ALA is required to make other omega-3 fats. Dietary sources of ALA include vegetable oils, green leafy vegetables, rapeseed (flaxseed) and nuts (walnuts and pecans). The ALA is used to synthesis Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) that are long-chain fats (unit 1). It is these fats which are associated with health benefits such as lower risk of heart disease (Mori, 2017).

The best way of ensuring players ingest enough EPA and DHA is to recommend for them to eat foods rich in these fats. Fish, and especially oily fish, are good sources of EPA and DHA. Oily fish, such as salmon and mackerel, have the highest levels of omega-3. White fish also contains omega-3 but at lower levels than oily fish. There are no specific daily recommendations for omega-3 intake, but as a guide, players are encouraged to ingest sources (Table 1) of omega-3 in their diet 2-3 times per week (Mori, 2017).

Table 1: Examples of food sources of omega-3 rich foods and good options of fat sources for the player's diet

Fish (Omega-3)	Non-fish alternatives	Other
Mackerel, tuna, cod, haddock, plaice, pollack, salmon.	Soya and soya products Green leafy vegetables Nuts and seeds Vegetable oils	Avocados Cheese Eggs Olives (oil)

Source: prepared by author.

However, studies are starting to look at daily doses (4-5 g) of fish oil on muscle sensitivity. In these studies, omega-3 has been provided in capsule form rather than food. This method allows studies to control the quantity of omega-3 provided, whereas levels are likely to vary in food. These studies have found dietary supplementation of 4-5 g of fish oil per day to improve muscle sensitivity to anabolic stimuli, resistance exercise and protein ingestion. Thus, the ingestion of omega-3, in combination with the ingestion of protein, may be an effective strategy in maintaining muscle mass or promote adaptation (McGlory et al., 2016; Smith et al., 2011). The ingestion of omega-3 fatty acids may also be an important consideration for the injured player in the return to play process, which will be discussed in later courses.

The ingestion of EPA may also be considered following matches, especially during periods of fixture congestion, to reduce eccentric exercise-induced muscle damage, due to the physical demands of match-play. Research has found that acute intake of a fish oil capsule high in EPA (750 mg EPA, 50 mg DHA), immediately after exercise designed to promote muscle damage, improves functional performance and perception of soreness in the days following exercise (Jakeman, Lambrick, Wooley, Babraj, & Faulkner, 2017; Tartibian, Maleki, & Abbasi, 2009). In a study specifically performed in football players, the influence of adding omega-3 (EPA: 550 mg, DHA: 550 mg) to a whey protein and carbohydrate containing beverage was investigated following eccentric (muscle damaging) exercise. The beverage composition of carbohydrate and protein was similar to that typically ingested by football players following training and matches. The player ingested the beverage either with or without the additional omega-3 for a 6-week period prior to the exercise test (Philpott et al., 2017). Although no differences in muscle function or football performance were observed between groups, the addition of the fish oil did improve perception of muscle soreness (Philpott et al., 2017).

Summary

- Fat is an important component of the player’s overall energy intake.
- Individual players will vary significantly on their capacity to use fat as a fuel during exercise.
- Players are advised against the use of “fat burning” supplements.
- Players are recommended to ingest meals rich in omega-3 fats twice a week.
- Acute intake of omega-3 may improve the recovery following muscle damaging exercise and perception of muscle soreness.

Disclaimer: Ian Rollo is an employee of the Gatorade Sports Science Institute, a division of PepsiCo, Inc. The views expressed in this course are those of the authors and do not necessarily reflect the position or policy of PepsiCo, Inc.

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