Energy Systems in Sports

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Abstract. Energy is defined as the ability to do work or cause motion. It has different forms like heat, light, sound, electrical energy, mechanical energy, and chemical energy. Metabolic processes in the human body use chemical energy. Adenosine triphosphate (ATP) is used as the source of energy for muscle contraction. ATP has high energy phosphate bonds and each bond stores about 11,000 calories. There are three energy systems for muscular contraction: a) Immediate energy system (Anaerobic System): Phosphogen system, b) Short-term energy system (Anaerobic glycolysis): Lactic acid system, c) Long-term energy system (Aerobic glycolysis). Football is the most popular sport in the world. It is categorized as intermittent exercise (frequent periods of intense work followed by periods of less-intense recovery). Top level players travel approximately 11 km in a 90 minute match. The exercise intensity is reduced and the distance covered is 5–10% less in the second half. Football is mainly dependent upon aerobic metabolism. Aerobic energy production accounts for more than 90% of the total energy consumption. The average work intensity is close to the anaerobic threshold (normally between 80–90% of HRmax in football players). In football there are periods of high-intensity activity where accumulation of lactate takes place. There is a sprint bout every 90 seconds, lasting 2–4 seconds. Sprinting constitutes 1–11% of the total distance covered during a match, corresponding to 0.5–3.0% of effective play time. Anaerobic episodes constitute a small part of the match, but are very crucial. During recovery, oxygen uptake remains elevated. If recovery periods are relatively short, VO2 remains elevated and the aerobic contribution to ATP resynthesis increases. There are no published data about the energetics of amputee football. The following assumptions can be made: slow and fast episodes of amputee football are slower than regular football; the energy needed to accomplish the same task is higher in amputees; the energy profile is similar.

Keywords. Energy systems, amputee football

Muscle Fiber Types

There are two types of muscle fibers in human skeletal muscle:

a) Type I (ST = Slow twitch) (formerly known as red fibers).
   1. Type Iia (Oxidative).
   2. Type Iib (Glycolytic).

b) Type II (FT = Fast twitch) (formerly known as white fibers).
In human muscle, all types of fibers are found in a mixed composition. The performance of a muscle depends on biochemical and morphologic features of the fiber type that constitutes the majority. Posture muscles, as an example, include mostly slow twitch fibers. Muscles of endurance athletes include mostly slow twitch fibers while muscles of athletes of explosive sports include mostly fast twitch fibers.

**Features of Slow Twitch Muscles**

a) Contraction is slow, its duration is long, strength is low. Better adaptation to submaximal long term exercise.

b) Low anaerobic capacity.

c) High oxidative capacity.

d) High myoglobin.

e) High mitochondria and high oxidative enzymes.

f) Resistant to fatigue.

g) High triglycerides.

h) High capillaries.

**Features of Fast Twitch Muscles**

a) Contraction is fast, duration is short, strength is high.

b) Anaerobic capacity is high.

c) Not resistant to fatigue.

d) Low myoglobin.

e) Low mitochondria and oxidative enzymes.

f) Low triglycerides.

g) Low capillaries.

Energy is defined as the ability to do work or cause motion. It has several forms like heat, light, sound, electrical energy, mechanical energy, and chemical energy. Metabolic processes including muscular contraction use chemical energy. During muscular contraction chemical energy is converted to mechanical energy. Adenosine triphosphate (ATP) is the main source of energy for muscle contraction. Adenosine triphosphate (ATP) includes high energy phosphate bonds (Adenosine - PO₄−PO₃−PO₃). Each bond stores about 11,000 calories.

\[
\text{ATP} \rightarrow \text{ADP} \rightarrow \text{AMP}
\]

**Energy Systems**

There are three types of energy systems for muscular contraction:

a) Immediate energy system.

b) Short-term energy system.

c) Long-term energy system.
1. Immediate Energy System

The first fuel used for the muscle contraction is stored ATP. Human body has 20–25 mmol/kg dry muscle (dm) of stored ATP. It is enough to fuel 1–2 seconds of maximal work.

\[
\text{ATP} \rightarrow \text{ADP} + \text{Pi} \quad \text{Energy}
\]

\[
\text{ADP} + \text{ADP} \quad \text{Adenylate kinase} \quad \text{ATP} + \text{AMP}
\]

The second part of immediate energy system is Phosphocreatine (PCr) or Phosphagen system. This energy system provides fuel for explosive activities which are primarily short duration, high intensity exercises. However, this system is active at the beginning of all exercise regardless of intensity. Intramuscular PCr stored in the human body is approximately 80 mmol/kg dry muscle. It is enough to fuel 10 seconds of maximal work and it is the primary fuel source for heavy resistance training.

\[
\text{PCr} + \text{ADP} + \text{H}^+ \quad \text{Creatine kinase} \quad \text{ATP} + \text{Cr}
\]

2. Short-Term Energy System

This energy system is also known as anaerobic glycolysis. This is the breakdown of glucose, mainly in the form of muscle glycogen, to ATP and lactate. Carbohydrates are either stored in the muscle as glycogen or delivered to the muscle in the bloodstream as glucose. Anaerobic glycolysis is used for times when oxygen is in short supply. It results in the formation of lactic acid, the byproduct of energy supply to the muscle. Each glucose molecule is split into two pyruvic acid molecules, and energy is released to form several ATP molecules providing about 30 to 40 seconds of maximal muscle activity in addition to the 10 to 15 seconds provided by the phosphagen system. The pyruvic acid will then partly break down further to produce lactic acid. An increase in lactic acid in the muscle can involve muscular fatigue and ultimately cessation of exercise. Anaerobic glycolysis peaks around the 5th second of maximal work. It can produce fuel for moderate heavy resistance training. If continued, lactic acid would result in muscular fatigue and ultimate stoppage of the exercise.

\[
\text{Glycogen} + 3 \text{ ADP} + 3 \text{ Pi} \rightarrow 3 \text{ ATP} + 2 \text{ lactate}^- + 2 \text{ H}^+
\]
3. Long-Term Energy System

This energy system is used for aerobic metabolism. During maximal work aerobic ATP resynthesis is achieved primarily through the oxidation of glucose. The chemical reaction for the oxidation of glucose is known as the Krebs cycle, citric acid cycle, or tricarboxylic acid (TCA) cycle. This system is often referred to as the oxidative system. The aerobic system is utilized for the sports that require an extensive expenditure of energy. Lots of ATP must be provided to the muscles in order to sustain the muscle power that an athlete needs to perform such events without excessive production of lactic acid. This fuel supply offers energy to the muscle through the use of continuous oxygen transport. Therefore, in the presence of oxygen, pyruvic acid breaks down into carbon dioxide, water, and energy. This system works at rest and during very low intensity exercise such as repetitions during resistance training for walking or running. This form of energy primarily utilizes fats (70%) and carbohydrates (30%) as fuel sources, but as intensity is increased there is a switch in substrate majority from fats to carbohydrates.

Glucose and glycogen are used when oxygen is present in large quantities. The oxidative system usually supplies energy for low intensity exercise lasting up to one and a half hours.

\[
C_6H_{12}O_6 \text{ (glucose)} + 6O_2 + 38 \text{ ADP} + 38 \text{ P}_1 \rightarrow 6 \text{ CO}_2 + 6 \text{ H}_2\text{O} + 38 \text{ ATP}
\]

Summary of Energy Systems

1. Anaerobic System/Without oxygen
   a) ATP-PCr = Phosphagen system.

   \[
   \text{ATP} \rightarrow \text{ADP} + \text{Energy} \\
   \text{ADP+PCr} \rightarrow \text{ATP+Creatin}
   \]

   b) Glycolytic system = Lactic acid system

   \[
   \text{Glycogen} \rightarrow \text{Lactic acid} + \text{ATP}
   \]

2. Aerobic System/With oxygen

   Aerobic glycolysis

   \[
   \text{Glucose+fat+protein+O}_2 \rightarrow \text{ATP}
   \]

Energy Efficiency of Carbohydrates and Fat

Oxidization of glucose produces 36 ATPs, while oxidization of palmitate produces 130 ATPs. In other words one mol glycogen (180 g) breakdown requires 134.4 lt O2, and
one mol palmitate breakdown requires 512 lt O2. Therefore one mol ATP synthesis from glucose requires 3,5 lt O2, and one mol ATP synthesis from fat requires 4 lt O2. Although fat produces more energy, glucose is more energy efficient when oxygen consumption is considered.

**Energy Sources at Rest**

During rest 2/3 of energy comes from fat, and 1/3 of energy comes from glucose. Protein’s contribution is negligible. Only aerobic energy sources are used during rest. Although anaerobic system is not effective, low levels of lactic acid can be found in blood due to the effect of the lactate dehydrogenase enzyme.

**Energy Sources during Exercise**

There are two major exercise categories:

a. Brief, high intensity exercise:
   - 100, 200, and 400 meters sprint.
   - 800 m running.
   - High intensity exercises with 2–3 minutes duration.

b. Lower intensity exercise performed for longer periods of time:
   - Running, cycling, swimming for longer periods.

1. **Brief, High Intensity Exercise**

   - Major source is glucose.
   - Fat utilization is less.
   - Protein’s contribution is negligible.
   - Anaerobic system predominates.
   - ATP-PCr and lactic acid systems are in charge.
   - Lactic acid accumulates and causes fatigue.

2. **Longer Period–Lower Intensity Exercise**

   - Aerobic system predominates.
   - Carbohydrates and fat are used.
   - Major source is carbohydrate up to 20 minutes of exercise
   - After 1 hour of exercise glycogen stores are depleted and fat becomes the major source

**Football**

Football is by far the most popular sport in the world. Due to its acyclical nature and intensity, it is classified as a high intensity intermittent team sport. It includes frequent periods of intense work followed by periods of less-intense recovery. During
competitive football match play, elite players cover a distance of about 10–12 km at an average intensity close to the anaerobic threshold, being 80–90% of maximal heart frequency or 70–80% of maximal oxygen uptake. The exercise intensity is reduced and the distance covered is 5–10% less in the second half of the football game. It is estimated that aerobic metabolism provides 90% of the energy cost of football match play. Therefore, it is a prerequisite in the modern game for the elite football player to have high aerobic endurance fitness.

Football includes explosive activities like jumping, kicking, tackling, turning, sprinting, changing pace, and sustaining forceful contractions to maintain balance and control of the ball against defensive pressure. There are periods of high-intensity activity where accumulation of lactate takes place. There is a sprint bout in a football game every 90 seconds, lasting approximately 2–4 seconds. Sprinting constitutes 1–11% of the total distance covered during a match corresponding to 0.5–3.0% of effective play time. Anaerobic episodes constitute a small part of the match, but they are very crucial. The average work intensity, measured as percentage of maximal heart rate (HRmax), during a 90-minute soccer match is close to the anaerobic threshold (the highest exercise intensity where the production and removal of lactate is equal; normally between 80–90% of HRmax in soccer players).

Football is basically a multiple sprint type exercise. The physiology of single sprint and multiple sprint seems to be different. During a single short (5-6 second) sprint ATP is resynthesised from anaerobic sources with a small (<10%) aerobic contribution. During recovery, oxygen uptake remains elevated to restore homeostasis via processes such as the replenishment of tissue oxygen stores, the resynthesis of PCr, the metabolism of lactate, and the removal of accumulated intracellular inorganic phosphate. If recovery periods are relatively short, VO2 remains elevated and the aerobic contribution to ATP resynthesis increases. However, if the duration of the recovery periods is insufficient to restore the metabolic environment to resting conditions, performance during successive work bouts may be compromised. In a football game each player performs 1000–1400 mainly short activities changing every 4–6 seconds. Activities performed are: 10–20 sprints; high-intensity running approximately every 70 seconds; about 15 tackles; 10 headings; 50 involvements with the ball; about 30 passes as well as changing pace and sustaining forceful contractions to maintain balance and control of the ball against defensive pressure. It was noted that the fullbacks sprinted more than twice as much as the central-defenders (2.5 times longer), while the midfielders and the attackers sprinted significantly more than central-defenders.

The muscular glycogen is the most important substrate of energy production during the matches. The contribution of the aerobic energy system is reported to be 28–40% during a 30-second sprint. The aerobic energy system contribution is also considerable during shorter bouts of exercise, and has been reported to be approximately 30% during sprinting over 12–22 seconds. Football exerts a strong demand on the reserves of muscular and hepatic glycogen because the players must run at random at different speeds and develop technical skills during the matches. It is evident that the anaerobic ATP production during short-duration sprinting is provided by considerable contributions from both PCr degradation and anaerobic glycolysis, confirming the significance of glycolytic activity during this type of exercise. The contribution of fat within the total metabolism of energy is up to a 20% in adult players. Lactate production increases during the intense efforts, nevertheless the periods of active recovery at sub maximum exercise levels allow its elimination continuously. The
relative contribution of anaerobic glycogenolysis is reduced during the performance of subsequent sprints, which is partially explained by an increase in aerobic metabolism. Sprint duration may significantly alter the relative energy system contribution during repeated-sprint exercise. Although the decisive actions of the sport are considered to be anaerobic activities, aerobic resistance can have a greater level of importance during recuperation periods than during the actual strength performance activity, especially when considering the randomization involved in the duration, activity time/pauses, distance and occurrence of intense physical efforts during the game.

During multiple sprint:
- Percentage of anaerobic glycolysis decreases.
- Percentage of aerobic energy increases.
- Percentage of PCr increases.

Amputee Football

There is no published data about the energy profile of amputee football. Below-knee amputees have run the 100 m in a little over 11 seconds. At this level of performance, amputee sprinting is a highly competitive sport, with many athletes training as much as their able-bodied counterparts. Apart from developing the necessary motor coordination, sprint training is undertaken by both able-bodied and amputee athletes to develop strength and power in the muscles of the lower-limb. Because below-knee amputees require the use of an artificial foot and ankle, both the benefit of training and sprint performance are affected by the design of their chosen prosthesis. Amputee football, however, is different from amputee sprinting, because it is performed without wearing prostheses. We can only make some assumptions about the energy profile of amputee football. Slow and fast episodes of amputee football seem to be slower than regular football. On the other hand, the energy needed to accomplish the same task is known to be higher in amputees. Therefore, we can expect a similar energy profile. Research should be done to elucidate the similarities and dissimilarities of amputee football and regular football.

References

Alvarado MU. Nutrition For Young Soccer Players. International Journal of Soccer and Science Journal Vol. 3 No 1 2005


Lopez JG, Marroyo JAR, Rabago JCM, Montesinos GJL, Vicente JM, Vicente JGV. Validity Of Lactic Acid In An Interval Stress Test (Probst Test) To Determine A Soccer Player’s Anaerobic Threshold. International Journal of Soccer and Science Vol. 2 No 1 2004
