The Marvelous Mitochondria

'Understanding the Cell's Energy Power Plant'

Len Kravitz, Ph.D.

The mitochondrion (or mitochondria in its plural form) is a specialized organelle found in most eukaryotic cells (cells that contain a nucleus), which are often referred to as a cell's energy power plant. Mitochondria are essential for human existence, and thus involved in numerous cell processes that rely on energy sustenance, such as cell growth, cell messaging, aging and replication (Schardt, 2008). And, for this same reason mitochondria are known to be associated with several diseases of energy demanding organs and tissues of the body including the heart, brain and skeletal muscle (Hood et al., 2006). Most human cells contain several hundred to a couple thousand mitochondria (Schardt, 2008). They have incredible bioenergetic capacity. For instance, Tonkonogi and Sahlin (2002) state that during cardiorespiratory exercise these microscopic organelles can increase their energy output 400 times beyond rest, which leads to a mitochondria oxygen consumption and utilization 100 times higher when compared to non-exercising states. This research column continues with a brief review on the mitochondria's vital energy function capabilities in the human body.

Mitochondria: From Anonymity to Notoriety

German cell and structure researcher Richard Altmann discovered mitochondria in the 19th century. Karl Benda, a German physician, later gave them the name mitochondria. Altman correctly hypothesized from his research observations that mitochondria (which he called bioblasts) had metabolic and genetic self-sufficiency characteristics (meaning they adapt independently to various stimuli). Lynn Margulis (previously Sagan) (Sagan, 1967), an American biologist from the Department of Geosciences at the University of Massachusetts Amherst is recognized for her theoretical explanation of mitochondria development with the endosymbiotic (from the Greek root endo, meaning inside and symbiosis meaning cohabiting) theory. According to this theory by

Margulis, mitochondria may have been the remnants of early bacteria that were engulfed by ancient eukaryotic cells about one billion years ago. Over time, mitochondria gradually evolved to become the energy-yielding organelle that is now present in eukaryotic cells. Notably, in the early 1960's scientists discovered that mitochondria had their own DNA, the genetic instructions used in the development and functioning of all known living organisms.

The Mitochondrion: Perspective from the Microscope

As seen in Figure 1., the mitochondrion has two cell membranes. The outer most membrane has distinct channels, which allow specific molecules to enter and exist. The inner membrane folds uniquely through the oval-shaped organelle. The inwardly directed folds of the inner membrane go toward the center of the mitochondria (known as the matrix), and are referred to as crista (cristae for plural) membranes. The cristae membranes house the protein sectors that shuttle electrons, which arrive from the tricarboxylic acid cycle (TCA, also called the Krebs cycle) and contribute to the energy yielding process. These electron shuttles are composed of distinct energy-transferring proteins, collectively referred to as the electron transport chain. The mitochondria have their own independent DNA, thus allowing them to adapt with gains in size and number. Thigh muscle cells have been shown to replicate 50% more mitochondria with 12 weeks of consistent, moderately intense aerobic exercise (Schardt, 2008).

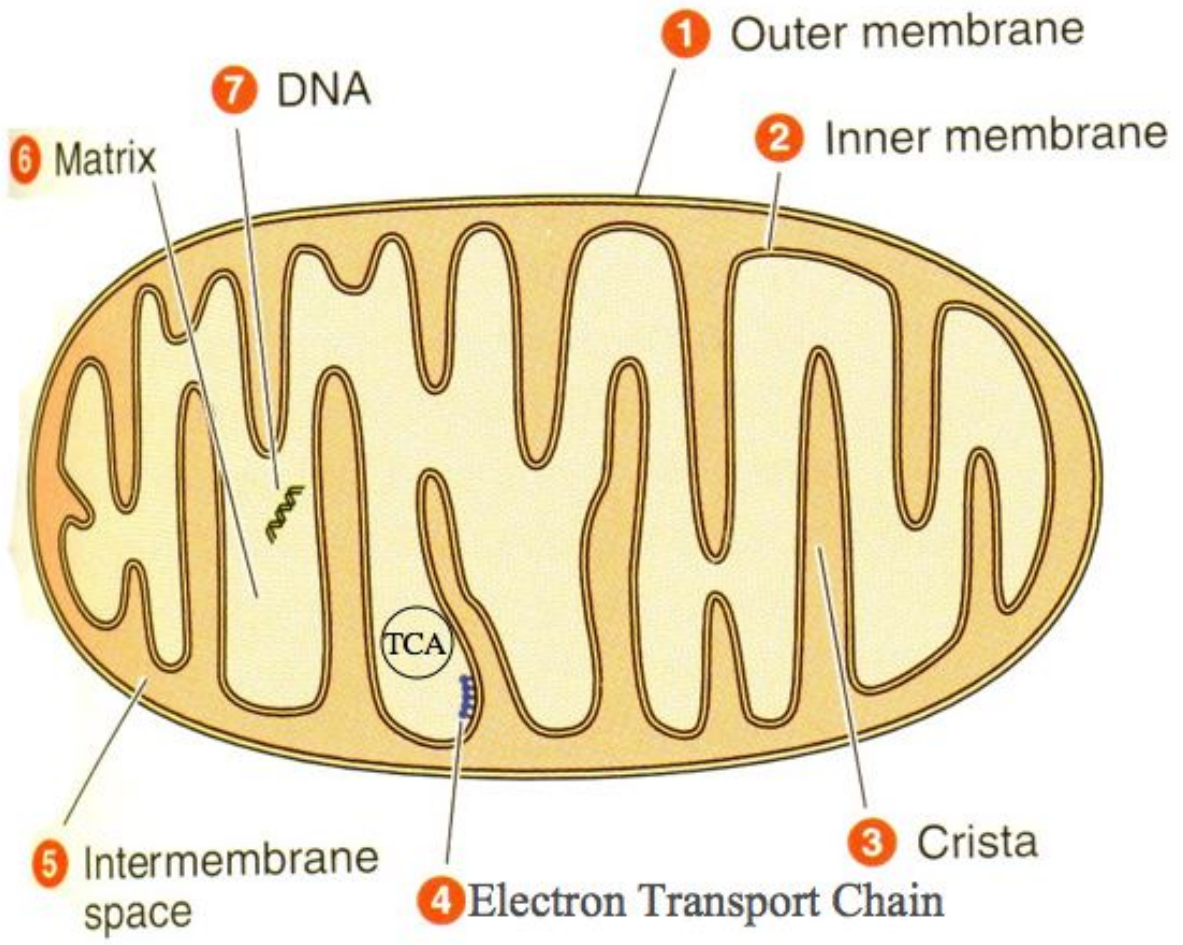

Figure 1. Mitochondrion Shape, Structure and Constituents

The Energy Factory Story of Mitochondria

Mitochondria are often (and accurately) referred to as the food-burning furnaces in a person's body cells (Schardt, 2008). Within the mitochondria, as the chemical bonds in fat (in the form of triglyceride), carbohydrate (in the form of glucose and glycogen) and protein (in the form of amino acids) molecules are broken up though metabolism, they begin to lose electrons, a process called oxidation. As a molecule is going through the oxidation process it is also releasing energy and heat. So, the common use of the term 'fat burning' in the fitness and weight loss industry is an appropriate analogy of what is happening to fat in the cell's mitochondria. Since energy is neither created nor destroyed (i.e., the first law of thermodynamics), biologists like to suggest the within the mitochondria furnaces the bonds in food stuffs (i.e., triglycerides, glucose, amino acids) are broken

apart with the energy being released and transferred into the synthesis of adenosine triphosphate (ATP). ATP is the form of energy that is then delivered to other areas of the cell (such as muscle proteins) to carry out cell processes to promote growth and sustain life (Schardt, 2008). Mitochondria, in effect, coordinate the chemical energy released from the oxidation of foodstuffs in a section of their inner membrane (known as the electron transport chain) through a complex system of metabolic steps that results in the synthesis of ATP. The ATP synthesizing process depends upon a steady supply of oxygen, which is why this process is aptly nicknamed 'aerobic metabolism' or 'aerobic respiration'.

Mitochondrion and Fat Burning: The Exercise Professional's Mighty Message to Clients

Perhaps one of the most important educational messages exercise professionals are able to share with clients is that with regular endurance training, mitochondria adapt by metabolically using more fat and less carbohydrate for fuel during exercise (Hood et al., 2006). A coincident secondary effect is that there is a reduction in the amount of metabolic acidosis produced in the muscles, because they are relying less on carbohydrate for fuel (Hood et al., 2006). Thus the exercising body is able to do more work, experience less fatigue and burn more calories with each work bout. This increase in fat burning capacity from endurance exercise is referred to as mitochondrial biogenesis (Hood et al., 2006). In fact, Menshikova et al. (2007) showed that sedentary obese (BMI >31 kg/m^2) men and women (ave. age = 41 yrs) doing moderate-intensity (60% - 75% maximal heart rate) physical activity (4 to 6 times a week, progressing from 30 to 40 minutes per session on a treadmill and cycle ergometer) for 16 weeks resulted in significant mitochondrial biogenesis adaptations. The obese subjects in this study were also placed on a 25% calorie reduction diet to help attain a 7% loss in body weight. Menshikova and colleagues discuss that an intriguing aspect of skeletal muscle physiology is that it has considerable metabolic plasticity, which means with consistent aerobic exercise there is a dramatic increase in blood flow, oxygen consumption and rate of substrate (food stuffs used by the cell for fuel) utilization within the mitochondria of muscle. The authors affirm

that the opposite is also apparent; with sedentary behavior skeletal muscle shows drop in oxidative capacity and increases in fat deposition, which are characteristics of insulin resistance and weight gain. Although most research demonstrating these prominent mitochondrial adaptations has been completed using aerobic exercise, Melov et al. (2007) states that resistance exercise may also show mitochondrial bolstering capabilities in older male and female populations.

Final Thoughts

Mitochondria are remarkably adaptable organelles within skeletal muscle that can impressively boost a muscle's capability to burn fat, improve insulin sensitivity (and thus help to manage or prevent pre-diabetes or diabetes), minimize fatigue and enhance their own capacity to synthesize fuel for physical activity and exercise (Menshikova et al., 2007). The great news is research shows that with young and older persons, mitochondria are most capable of improving their biological function and thus enhancing the quality of life of the exercising individual (Melov et al., 2007). It's never too late to start moving.

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