Muscle Fiber Types•

I. Fiber Types

A. Introduction. It has long been known that vertebrate animals possess at least two distinct types of skeletal muscle fibers.

1. These types are most evident in non-mammals -- birds, reptiles, amphibians and fish.

2. Since time in memorial, people have realized that muscles in these types of animals were either dark (red) or light (white). Keen observers also quickly realized that the type of muscle correlated with the type of activity the muscle was used in.

a. **Red types** tended to be found in muscles used for sustained activity. Examples include the leg muscles of ground birds such as chickens and turkeys, the flight muscles of highly active or migratory birds (*e.g.* hummingbirds, gulls, hawks), and the cruising muscles of some fish (muscles near the backbones of tuna and sharks).

b. **White types** were associated with powerful activities that could only be sustained for short periods of time. Examples include the flight muscle of birds capable only of short (but often powerful) flights such as chickens and turkeys, "sprinting" muscles in fish (the majority of most fish), jumping muscles in frogs and much of the body of sluggish animals such as many snakes.

3. People also knew that mammal muscles were not so sharply delineated. They could be distinguished from each other in terms of some being redder than others, but all were at least a healthy pink. However, when individuals began looking at muscles with microscopes, they found that mammals like ourselves have two or three different kinds of muscle fibers within each of their muscles. Thus, the fundamental difference in appearance between mammal muscles and those of other vertebrates is that in mammals, all of the fibers are mixed together within each muscle. There are no distinctly dark and light muscles. All muscles are pinkish red and all are a mix of dark and light fibers.

4. This led to further study and the creation of a system for classifying different muscle fibers (remember, a muscle fiber is a muscle cell). The scheme is based on research on other species of mammals, and on human tissue samples taken both from cadavers and by **muscle biopsy**.

a. Muscle biopsy is an invaluable technique whose widespread use owes to a number of Scandinavian physiologists who used each other for subjects.

b. It is useful because it gets a tissue sample from a living person. Repeated samples can be taken so that muscle adaptations to training regimes can be studies or single samples can be taken from athletes for studies correlating their muscle's characteristics with their performance.

c. In a muscle biopsy, a rather large needle is inserted in the muscle moved around a bit and withdrawn. A sample of the muscle remains in the needle (rather like taking an ice core sample from a glacier). This sample can be removed, studied under the microscope and biochemically.

d. The technique is not particularly damaging, especially if not performed too many times and with modern equipment (finer needles which are permitted by more sensitive techniques to analyze the sample).

B. **Factors used to define fiber types**:

1. **Speed**: How fast can the fiber contract and relax? There are at least two factors that help determine speed of contraction:

(a) **Velocity of the myosin ATPase reaction**. Recall that part of myosin is an enzyme capable of breaking down ATP. The rate at which this process occurs will be an important determinant of how fast crossbridges can cycle - it determines how rapidly the myosin head is reset after letting go of actin and therefore how quickly the myosin can re-attach to actin. The maximum rate of the myosin ATPase from a piece of muscle tissue obtained via biopsy can be measured using biochemical techniques.

(b) **The capacity of the muscle fiber to release Ca^{++} and to pump Ca^{++}**. The two tend to be related. Muscle fibers that can release more Ca^{++} are also capable of pumping more. However, the maximum rate of release is always greater than the time it takes to gather up the Ca^{++} after a contraction. Clearly the faster that Ca^{++} is released the more quickly the muscle can begin to contract. And the more Ca^{++} that is released, the more forcible the contraction (within limits). It is a general trend that cells that release Ca^{++} more rapidly tend also to be able to gather it up (pump it into the SR) faster.

2. **Strength and ability to get rid of wastes and obtain oxygen**:

(a) One of the best measures of strength of a fiber is the fiber's **diameter**. Muscle fibers with greater diameters have more sarcomeres packed into the cell (in parallel to each other) and therefore are far stronger. A partial analogy is a rope: to make a rope stronger, we put more strands in parallel, resulting in a thicker and stronger rope. Likewise, in muscle -- all the fibers in parallel must eventually exert their pull on the same tendon. The force increases as more are added (and as the muscle gets thicker).

(b) On the other hand, muscle cells with greater diameters have more trouble getting nutrients, oxygen and wastes in and out of the cell. Here is why.

(i) Everything that enters the muscle fiber must come through the sarcolemma.

(ii) As the muscle cell gets thicker (let's say its diameter doubles), its volume increases by the cube of the radius. So, if diameter doubles, radius doubles (2) and volume increases by a factor $2^3 = 8X$.

(iii) On the other hand, the area of the sarcolemma only increases by the square of the radius. So, if radius and diameter double, the surface area of the cell increases by a factor of $2^2 = 4$ times.

(iv) So, notice that while both the surface area and volume are increasing, the volume increases much faster. The surface area available to get oxygen to a given amount of volume **decreases** as the cell gets larger. We can see this by looking at the surface to volume ratio. Recall that when our cell doubled in radius (and diameter), the volume went up 8 fold and the surface area 4 fold. The surface to volume ratio is only 4/8 or 1/2 what it was before the cell doubled in size!

(v) So, big cells run into problems getting rid of wastes and obtaining oxygen (and to a lesser degree nutrients -- but that is a story for later).

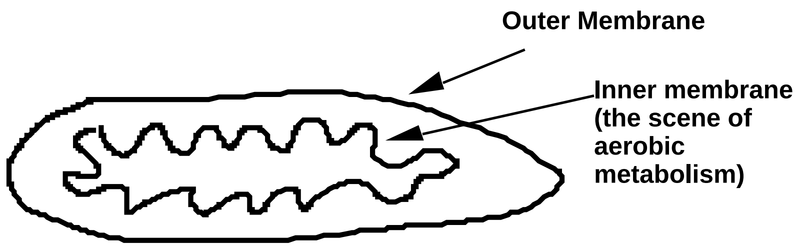
3. **Metabolic Characteristics**: These are related to the types of fuel a muscle can use, the extent to which it can use oxygen, and the types and amounts of waste products produced. These processes are responsible for breaking down complex molecules, removing some of the energy stored in them, and then using it to make ATP from ADP and Pi. As we will see in more detail later in the course, the two most important examples of ATP-generating metabolic processes occur in different parts of the muscle.

(a) **Capacity for oxidative metabolism**.

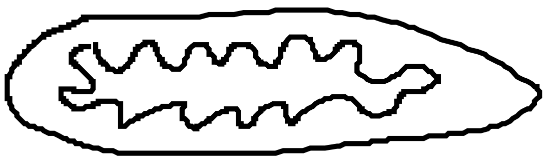
(1) The only place in a muscle fiber (or any other cell) where oxygen is used to break down large compounds for energy is the **mitochondria**.

(2) These organelles are extremely interesting. They contain their own DNA (genetic material), they divide like cells, they make their own proteins. Essentially they act like little cells inside larger cells (for example, the muscle cell). In fact nearly all available evidence suggests that early in evolution (perhaps 1.5 billion years ago) aerobic bacteria started to live inside of larger primitive cells that possessed nuclei. These bacterial eventually became an indispensable part of the larger cells. The larger cells in turn became the progenitors of all animals, plants, and fungi. But enough of this.

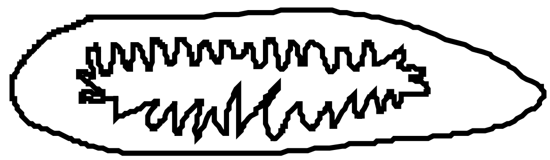
(3) Mitochondria look like this:



All of the reactions (and therefore the enzymes catalyzing these reactions) that use oxygen occur on the inner membrane. When an individual increases her/his aerobic fitness this membrane becomes more folded. This increases the surface area of the inner membrane and increases the capacity of a given mitochondrion (singular) to use oxygen to generate ATP.



Couch Potato Mitochondrion



Aerobically Fit Person's Mitochondrion

Another thing that happens when one becomes more aerobically fit is that more mitochondria are produced. Thus, one can look at a muscle fiber under a microscope and guess its capacity for aerobic reactions by looking at the number of mitochondria and the degree of folding of their inner membranes. In fiber types that are specialized for aerobic metabolism, the % of their volume that is mitochondria may approach 40%.

(4) There are at least two other factors which tend to go along with mitochondrial number in determining the oxidative capacity of muscle. These factors are:

(a) **blood capillary density**: mitochondria potentially require large amounts of oxygen. They also produce large amounts of CO_2 (carbon dioxide) which must be removed. Thus, the number of blood capillaries (the vessels that actually exchange gases and nutrients between blood and tissues) is important in determining oxidative capacity. We normally measure this as the density of capillaries -- the percentage of a tissue that is made up of capillaries. More capillaries usually means better oxidative ability.

(b) **myoglobin content**: myoglobin is a carrier protein. It acts somewhat like an enzyme in the sense that it has a site that a specific molecule (oxygen in this case) can bind to. However, it does not catalyze reactions but instead simply carries the oxygen. Myoglobin is closely related to the red protein hemoglobin found in red blood cells. It is also red. The more myoglobin a muscle fiber contains:

(i) the faster that oxygen can enter the muscle fiber from blood

(ii) the greater the reserve of oxygen in the muscle fiber (more about this in a couple of weeks).

(b) **Capacity for Glycolysis**:

(1) Unlike the oxidative reactions which are fixed in the inner membrane of the mitochondria, glycolysis reactions are spread throughout the sarcoplasm. The enzymes for this metabolic pathway (about 10) are simply dissolved in the liquid part of the cell that surrounds the sarcomere and all other structures in the fiber. The only way we can determine the capacity for glycolysis is to remove the enzymes from a biopsy sample and then use biochemical techniques to see how fast the reactions of glycolysis occur under ideal conditions. The faster this rate, the more enzyme is present and the greater the glycolytic capacity.

(2) It is worth realizing that glycolysis may be associated with either aerobic or anaerobic processes. Here is a quick overview -- we'll learn a bit more detail in a week or so:

(a) Glycolysis always starts with glucose or some very closely related sugar.

(b) It eventually breaks the glucose down into two large molecules -- these are the waste products of glycolysis. These waste particles differ according to whether the glycolysis is aerobic or anaerobic:

(i) **If glycolysis is aerobic**, the waste products (called pyruvic acid) are immediately broken down by the mitochondria. Thus, they do not accumulate in the muscle cell. Furthermore, we will see that a great deal of energy is taken from the pyruvate molecules when they are broken down and much of this energy is conserved for use by the cell as ATP.

(ii) If t**he glycolysis is anaerobic**, the waste products are molecules of **lactic acid**. This substance is not broken down further in the muscle. Since it is an acid, it releases large amounts of hydrogen ions (H^+) which have profound effects on the proteins of the muscle and which cause fatigue.

(c) In both the aerobic and anaerobic versions of glycolysis, a small amount of ATP is formed from ADP and Pi. This ATP, of course, can be used to fuel the ATP-requiring events of muscle contraction.

C. **Fiber types in the human body**:

1. Physiologists have named three fiber types in mammals. They are distinguished from each other based on the characteristics listed above. A given muscle is a mix of these types.

2. The names of the types and their synonyms follow. Please know all of these synonyms.:

(a) **Type I**, also known as **"red"**, **"slow twitch"** and **SO** (**slow oxidative**) and "**fatigue resistant**".

(b) <u>**Type IIa**</u>: also called "**red"**, "**fast twitch**" and **FOG** (**fast oxidative glycolytic)** and "**fatigue resistant**". **Note:** although these fibers are common in most kinds of mammals, they are rare in human muscles (contrary to what your book implies).

(c) <u>**Type IIb**</u>: also called "**white"**, "**fast twitch**" and **FG** (**fast glycolytic)** and "**fatigue prone**". Please note that these fibers are not really white -- they are a pink color.

We will pay most attention to types I and IIb. We will see in the next class that there are "intergrades" between I and IIb that while not true IIa fibers share many of IIa's characteristics. This is probably the source of confusion in your text book.

3. The table below summarizes the characteristics of the different fiber types.

(a) <u>**The measures are relative**</u>. Thus, when Myosin ATPase is characterized as being slow in type I fibers, this means that it is slower than the myosin ATPase found in fast fibers (IIa and IIb). in <u>untrained</u> subjects.

(b) Training changes most of the characteristics listed in the table (the only factor <u>probably</u> not affected by training is myosin ATPase velocity). However, <u>**usually but not alway**</u>s the relative positions of different fiber types remain the same, even after training. More about this when we deal with training.

(c) You should know and understand this table (see next page)

	Type I: Slow Oxidative (SO, red) Slow Twitch Fatigue Resistant	**Type IIA: Fast Oxidative Glycolytic (FOG, red) Fast Twitch Fatigue Resistant**	**Type IIB: Fast Glycolytic (FG, white) Fast Twitch Fatigue Prone**
Myosin ATPase Reaction velocity	Slow	Fast	Fast
SR Ca^{++} pump and Release (gate) capacity	Moderate	High	High
Diameter (relates to strength and diffusion distance)	Moderate Surface/Volume is high	Moderate Surface/Volume is intermediate	Large Surface/Volume is low
Oxidative capacity: mitochondrial content, capillary density, amount of myoglobin	High (mitochondria may occupy as much as 40% of the fiber volume) Large amounts of myoglobin. Together with the mitochondria, this makes the fiber reddish in color.	High	Low (mitochondria may occupy as little as 1% of the fiber volume) Very little myoglobin
Glycolytic capacity	Moderate	High	High

(d) A few comments on the table.

(1) Notice that there are at least two different types of myosin in the body. This is shown by the differences in myosin ATPase between slow and fast fibers. Thus, there are at least two different myosin genes (there is a gene for each specific type of protein). These same genes are present in all cells but in different cells, different genes are activated. So, the gene for the myosin with the "slower" ATPase is active in Type I fibers while the gene for the myosin with the faster ATPase is only turned on in Type IIa and IIb fibers.

(2) Notice the general pattern of characteristics of type I and IIb fibers go along nicely with their (many names). We should characterize them as:

(a) **type I**: oxidative, relatively slow and less forceful, hard to fatigue, dark in color. These fibers can use any type of fuel to make ATP (although they prefer glucose -- more about this later).

(b) **<u>type IIb</u>**: glycolytic (they have virtually no mitochondria and therefore cannot use O_2 even when it is available), fast onset and offset twitch, very strong, but easily fatigued since they produce lactic acid (no aerobic glycolysis), have low surface to volume relationships, and few blood vessels. We will see later that these cells must rely on glucose as fuel -- their abilities to use fat is very poor.

(c) **<u>type IIa</u>** -- intermediate between I and IIb, we'll tend to ignore these and think more about **<u>"large type I fibers"</u>** in their place.

4. Other comments about fiber types:
   a. The percentage of each fiber type differs:
      (1) in different muscles
      (2) in different individuals
      (3) there is a correlation with certain exceptional fiber type profiles and certain sports in <u>elite</u> athletes. However, this correlation is not absolute. There are many cases of world class athletes who do not have the "ideal fiber type" for their sport. Thus **<u>fiber type is not destiny in athletic performance</u>**. This is certainly not true in most athletes and is not even strictly true with elite athletes.
   b. <u>Differences between individuals in fiber types</u> of their muscles seem to be determined **<u>largely by genetic factors</u>**. There is **<u>equivocal evidence that training may cause the conversion of some fibers from one type to another</u>**. More about this later when we talk about training for strength and for aerobic condition and when we talk about individual differences.