MOXY
MUSCLE OXYGEN MONITOR

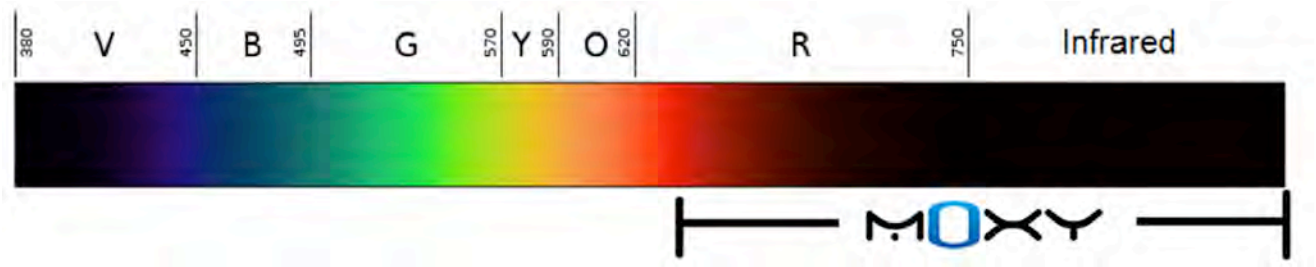
# The Science Behind Moxy

# HOW DOES MOXY MONITOR WORK?

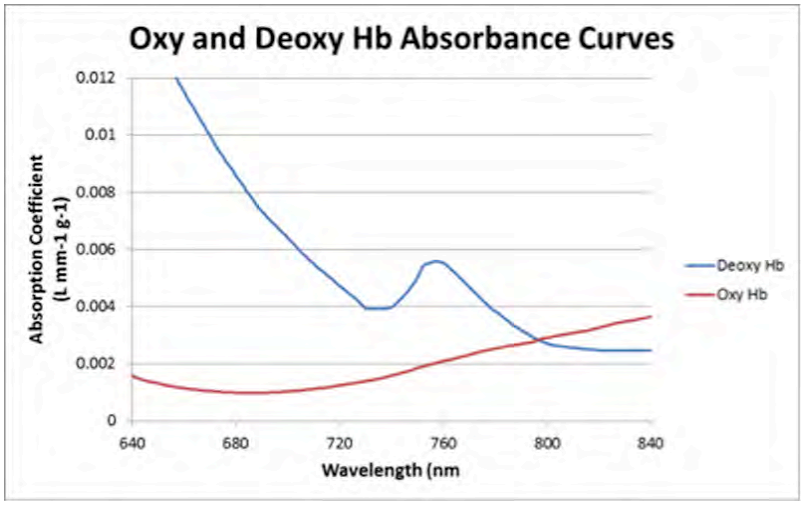
Moxy Monitor works by shining near-infrared light onto the skin and detecting some of the light after it has travelled into the muscle tissue and returned to the surface.

Light travels through tissue especially in the Red and Near-Infrared region of the spectrum. As it moves through the tissue, light scatters. This scattering is caused primarily by the differences in the index of refraction inside of the cells. This is why your hand glows red when you hold it over a flashlight.

The visible light spectrum ranges from about 380 nm on the violet end to about 750 nm on the red end. Moxy Monitor utilizes four separate light sources that cover the wavelength range from 630 to 850 nm.

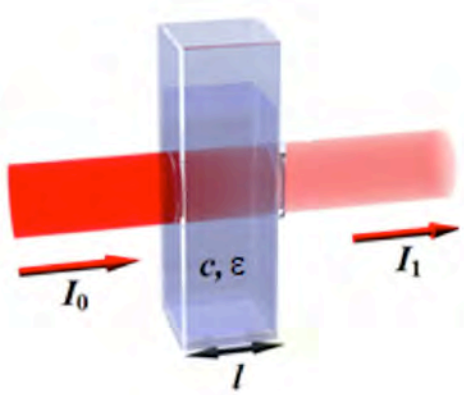



There are two reasons why this wavelength region is useful for measuring muscle oxygenation. First, light can travel far enough in tissue to get down to the muscle and back out. Second, oxygenated and deoxygenated hemoglobin have different absorbance spectra in this region. One could say they are a different “color,” recognizing that such a term usually applies to human perception of visible light.




The absorption spectra of oxygenated and deoxygenated hemoglobin.

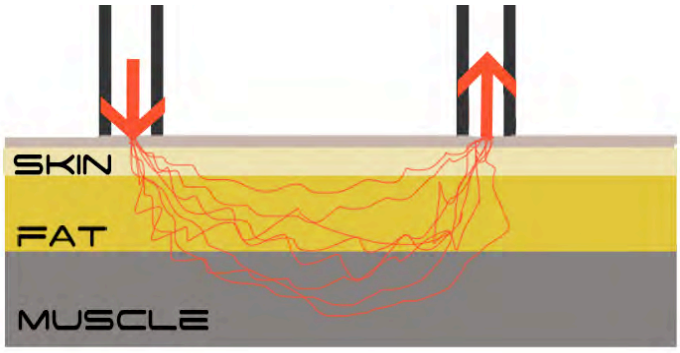
Chromophores are groups of atoms within a molecule that absorb light differently at different wavelengths. Oxy- and Deoxyhemoglobin are chromophores. It is possible to make quantitative measurements of the concentrations of chromophores using the Beer-Lambert Law.




$$\log \frac{I_0}{I_1} = \varepsilon l c$$

A beam of light is passed through a sample to be measured. The amount of light that is absorbed is the logarithm of the starting intensity divided by the intensity that exits the sample. Epsilon is the molar absorptivity which is a property of the chromophore and is available in published literature. l is the path length that the light travels through the sample. By measuring the light absorbed by the sample with several wavelengths of light and using some mathematical analysis such as partial least squares, chemists routinely measure the concentrations of mixtures of chromophores.

Moxy also uses the Beer-Lambert Law for its measurements. However, this metric poses a significant difficulty. Light doesn't pass straight through tissue, making it difficult to discern path length. In fact, light travels many different path lengths on its way from the emitter to the detector. This is further complicated by the fact that the path length shows variability at different wavelengths and in varying tissue types such as skin, fat, and muscle.




Light is emitted into the tissue at one location and then is detected at two locations, 12.5 and 25 mm from the emitter. This schematic illustrates the emitter and one detector, however it only shows the light that reached the detector. Light scatters in all directions, and the vast majority of it is lost. As little as one-millionth of the emitted light actually reaches a detector.

The Moxy uses four Light Emitting Diodes (LEDs) for its light emitter. The four LEDs fire in rapid sequence, and the light intensity is recorded simultaneously at each of the two detectors.

Over the years, researchers have developed ways to overcome the problem of unknown path length in order to measure chromophore concentrations in tissue. Very sophisticated instruments have been built to measure the time of flight of a light pulse through tissue. However, timing how long it takes light to travel a couple of inches requires a very expensive stopwatch.

A less-sophisticated technique attempts to calibrate on human subjects by inducing high and low oxygenation states and correlating measured light reflection with the oxygenation measured from blood draws. This approach has several problems. The optical measurement occurs in the capillaries, but the blood draw comes from the veins, where the oxygenation state is different. Also, this method can only practically cover a small portion of the variability in tissue such as skin color and fat layer thickness.

Another technique developed involves a tissue “phantom.” Human subjects are replaced with an apparatus that mimics the optical properties of human tissue. Typically, the phantoms have limited similarity to human tissue.

To overcome the path length issue, Moxy has developed a proprietary new technique. The calibration of the Moxy device is based on a mathematical model of how light propagates through tissue. This model is able to account for a wide range of variations in tissues.  It is perplexingly complex and tedious to implement, but the payoff is worth the effort.

This algorithm allows us to eliminate the expensive optical components required by certain techniques, and remove the guesswork of others, allowing for accurate readings on muscle over a wide range of skin and fat-layer conditions.

Moxy measures the ratio of the oxyhemoglobin concentration to the total hemoglobin concentration in the muscle and reports it as a percentage, which is $SmO_2$.

# WHAT IS $SmO_2$?

$SmO_2$ stands for muscle oxygen saturation. It is the percentage of hemoglobin that is carrying oxygen in muscle tissue.

Hemoglobin is the molecule in red blood cells that actually carries oxygen from the lungs to where it is needed in the body. Hemoglobin responds to chemical signals to drop off oxygen where it is needed. Hemoglobin's most common states are oxy and de-oxy.

The measurement of $SmO_2$ takes place in the capillaries of the muscle. This is where the oxygen is being consumed. $SmO_2$ can be thought of as a measure of the balance between supply and demand for oxygen in the muscle. When you first start to exercise, oxygen demand increases, but the heart hasn't had a chance to speed up, and the blood vessels in the muscle haven't dilated. The $SmO_2$ drops quickly in these conditions.

As you warm up, your heart rate increases, and the blood vessels in the muscle dilate to allow more blood flow, resulting in a slight rise in $SmO_2$ levels. When you stop exercising, the demand for oxygen suddenly falls, but the heart rate is still elevated and blood vessels dilated. At this time, a rapid increase in $SmO_2$ is observed.

Generally, higher levels of exertion in the muscle lead to lower $SmO_2$. The $SmO_2$ value is also affected by other factors such as the hemoglobin dissociation curve shifting and other chemical and neurological factors.

# HOW IS THIS DIFFERENT THAN A PULSE OXIMETER?

The pulse oximeter is widely recognized as the small finger clip often used to monitor hospital patients. Much like Moxy, it works by measuring the color of blood. However, the pulse oximeter keys in on pulsations caused by the arteries expanding and contracting with each heartbeat. In this way, it measures only arterial blood. Essentially no oxygen is consumed in the arteries from the time blood leaves the lungs until it reaches the capillaries. This means that the pulse oximeter records the same reading on a toe, finger, or earlobe readings that do not change when you exercise. Generally, the lungs are able to oxygenate the arterial blood to 85% to 100% saturation. However, lower arterial saturation is possible at high exercise intensity, at altitude or when the blood chemistry shifts the hemoglobin dissociation curve to the right.

Pulse oximeters are really used to make sure you're still breathing properly. Pulse oximeters typically use two wavelengths of light emitter and have one detector.

In contrast, Moxy employs a digital filter to reject the pulsating signal, uses four wavelengths of light emitter, and measures light with two detectors. This novel approach allows Moxy to measure blood in the capillaries rather than in the arteries.

The Moxy Muscle Oxygen Monitor system utilizes a complex algorithm to measure the oxygen saturation deep within exercising muscle tissue. Moxy measures $SmO_2$ non-invasively and in real-time. Moxy is totally portable, so an athlete can use it anywhere.

Moxy provides accurate $SmO_2$ data that is highly useful in guiding exertion levels during exercise to keep muscles in the desired metabolic state.


IT TAKES MOXY