SOARING Rx

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How Oxygenation Works

Lack of oxygen dulls the mind and judgment, slows the reflexes, weakens the muscles, and takes away our higher faculties. The higher one goes, the more serious are these effects. Too many people forget this exactly at a time when they should be most responsive to the danger. (Houston CS. What price a summit? Wilderness Environ Med 1996; **7:287**–8.)

Long ago, during an after-landout process, I discovered that the soaring world is inhabited by two species: the Analysts, who are fascinated by how things work and are happy to spend indefinite time satisfying their curiosity; and the Consumers, who are here to fly, and seem to believe that the Analysts are being distracted from "What's Really Important".

This column is aimed at the How-it-Works folks. You may read it, though, if you're not part of that club. Those of us who are Consumers sometimes encounter surprise endings, based on what I've seen. However, surprises in aviation are not always thrilling, so you might put on an Analyst hat while reading this; it's a good thing, and we won't insist you make it a habit.

As you all know, we breathe. Pretty regularly. Continuously. This, I'll call "ventilation." Its function is to get rid of carbon dioxide, a product of energy creation, and to inhale oxygen, the easy half of energy (the more difficult half being fuel).

We function – thinking, movement, growth, immune protection – using energy extracted from fuel through burning it in finely tuned, tightly regulated little furnaces in each cell, the mitochondria. The firewood, we eat; the oxygen, we breathe. These are married and consumed in the mitochondria to let us function. This fire I'll call "respiration." If the fire goes out, we quickly wilt.

The standard fuel is glucose – grape sugar to the tongue – an orderly assemblage of 6 carbon and 12 hydrogen atoms, plus 3 oxygens to help its shape. As you learned in biochemistry, this is disassembled by the "Krebs cycle" and the "Electron Transport Chain" into water and carbon dioxide, each glucose molecule yielding, through the process, up to 39 little packets of energy, ATP.

In general, every metabolic process in our cells happens through a multi-step assembly line that precisely shapes the output and permits fine control. "Respiration" is a bucket brigade of complex proteins that pass electrons from glucose to oxygen, forming water and carbon dioxide. The carbon dioxide we exhale, the water, we recycle. ATP is produced, providing energy for thinking and manipulating the aircraft controls in the graceful and skilled movements we're so used to.

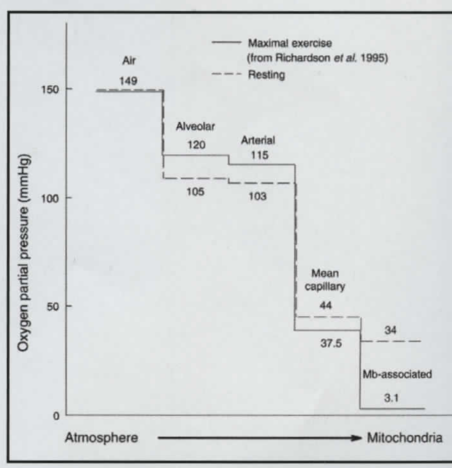
(It's fascinating that *iron* is central to this whole process: it's part of the hemoglobin that carries oxygen to cells, and it's part of the cytochromes that are in the electron bucket brigade. Thus if you're anemic and iron deficient, you actually lack energy, both from inadequate oxygen transport and from inadequate cellular "respiration.")

Now, the simple reason you have an oxygen bottle in that glider is that your friends and heirs are very interested in your exercising good judgment and in having a successful flight, not to mention the worried people over whose houses you fly and who write letters to the NTSB when we do things that make them scared.

To produce energy, the oxygen that starts in the ambient air must be delivered to the enzymes in the mitochondria. That delivery depends on a sequence of steps. If one or more of these steps is disrupted or sub-optimal, the pilot may be compromised. Here is what you need to succeed:

- Adequate amount of oxygen, measured by its atmospheric pressure ("partial pressure") in the air you inhale.
- Effective ventilation, to exhale stale air and to bring high-oxygen air into your lungs.
- Unhindered diffusion of oxygen and carbon dioxide across the lung's alveolar membrane. This thin membrane keeps our blood from leaking out our trachea, yet must allow gas through easily.
- Uptake of oxygen by the hemoglobin in red blood cells.
- Blood flow past the air sacs in the lung (the "alveoli").
- Blood flow (adequate pump function, adequate pressure, unrestricted flow) to the smallest blood vessels, the capillaries, where complementary gas exchange occurs.
- Hemoglobin must release oxygen at the capillaries, so it can diffuse across the capillaries' walls into the interstitial fluid between cells.
- Oxygen must diffuse in, carbon dioxide must diffuse out from the interstitial fluid in which all our cells are bathed.
- Cells must take up oxygen and it must enter the cellular mitochondria.

The partial pressure of oxygen naturally decreases at each of these steps, like a brook tumbling down a mountain, as shown in the first figure. This has been called "the oxygen cascade." A deficiency of any step in this cascade can cause damage downstream. (To you, dear reader.)

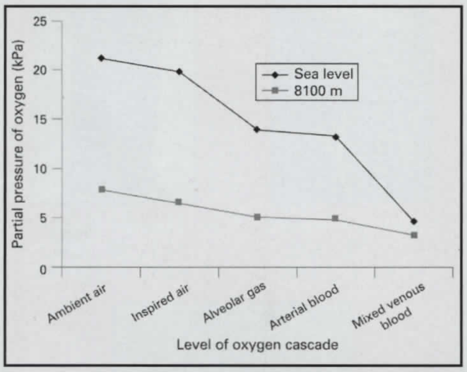


(Reference: Richardson RS, Duteil S, Wary C, Wray DW, Hoff J, Carlier

PG, J Physiol, March 1, 2006 **571:** 2 415-424)

This oxygen-cascade figure shows that during exercise we can extract more oxygen from our blood than at rest. That's important when we exercise, but we are not exercising in the cockpit: the point I want you to notice here is that there's a dramatic drop of oxygen partial pressure from lung (alveoli) to cells (mitochondria). The low cellular oxygen pressure decreases with altitude, or with any compromise to our delivery system. You can 'be a man', and go without supplemental oxygen as long as it's legal – or, if you don't care about rules, as long as you can function. (Only, be aware that the rare glider pilot has had brain damage from the effects of high altitude, when the "bends" have combined with hypoxia.)

The second figure shows the difference between sea level and 8100 meters (about 24,000 ft) on this oxygen cascade. This figure is for people acclimatized to high altitude, not for the glider pilot who's just ridden a 10-knot wave until his nails turned violet.



(Reference: Beall CM, PNAS May 15, 2007, **104,** Suppl 1, 8655-8660.)

The main things affecting this cascade are the partial pressure of oxygen taken in (read: bottle and mask or cannula), and the ability of the hemoglobin to take up *and release* oxygen ("oxygen dissociation.")

We talk often, in aviation, about oxygen supplementation, but we don't mention things *within ourselves* that can limit its effectiveness. Here's a short list:

Site Defect

Airway: ventilation

Airflow hindered by plugged nose, big tonsils, obesity

Lungs: ventilation

Fluid, inflammation (asthma, bronchitis, pneumonia)

Lungs: gas exchange

Chronic lung disease, esp. from smoking

Blood lack (anemia)

Decreased oxygen-carrying capacity

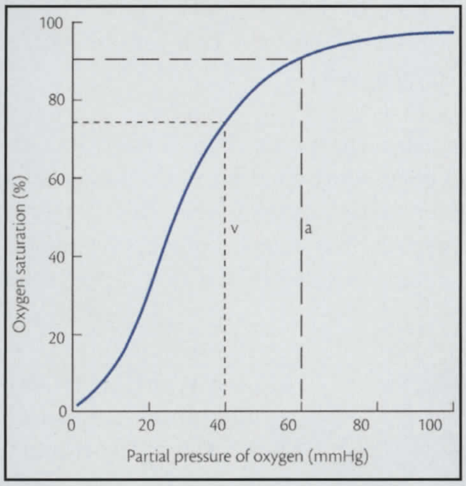
Pump failure (heart)

Poor delivery to tissues for several reasons

Blood

Hemoglobin fails to accept or release oxygen well.

This last point is an important one. Under some conditions, the blood does not release oxygen well. This is represented by a famous graph, the *oxygen dissociation curve.* In this figure, the letter 'a' indicates the normal status in the **a**rteries 'v' the normal status in **v**eins.



(Reference: Oxford Textbook of Medicine, 5th ed. 2010, Oxford University Press, Oxford, England)

The high flattish part of this curve illustrates the fact that when oxygen partial pressure is high (in your lungs, for example), hemoglobin turns sticky for oxygen; the ski-slope part of this curve portrays the fact that when the oxygen partial pressure is low (in your brain, for example), the hemoglobin tends to lose its grip, and oxygen is released. Cool, eh? Almost like it's meant to work that way. Therefore, normally hemoglobin takes up oxygen well in the lungs, and gets rid of it well in the tissues.

This curve also implies that as altitude increases (lower partial pressure); hemoglobin does not take up oxygen as well.

Several things affect the stickiness of hemoglobin for oxygen; some reduce the ability of hemoglobin to *release* oxygen to the tissues. This greatly reduces the effectiveness of any supplemental oxygen you might use.

• *Hyperventilation.* This raises the pH of blood, making hemoglobin stickier even while raising the oxygen content within the lung; the net effect is less oxygen delivered to hungry cells, such as our brain.

• *Carbon monoxide.* This ties up a fraction of the hemoglobin, decreasing the amount of oxygen transported, and makes hemoglobin stickier for oxygen, hindering its release to tissues. Carbon monoxide exposure is mainly from smoking and from engines. This is a risk to tow pilots, who have extra exposure due to slow airspeed, high nose attitude, and open cowl flaps. CO levels in my airplane are about four times as high during climb as during cruise. The fact that CO binds irreversibly to hemoglobin means that its effect is long lived (red cells are recycled after about three months.)

• *Body temperature.* Fever helps release oxygen to the tissues, hypothermia hinders its release. Getting cold reduces the benefit you get from supplemental oxygen.

• *Anemia.* When we're anemic, the amount of oxygen carried is less, but it's released more readily (though not enough to make up for the anemia).

Here's the point: all your cells will be happier and will work better – especially those important ones in your brain – if they have lots of oxygen. Of course, you use oxygen even when it's not required by the FARs, because it makes you so much smarter. However, you shouldn't go to altitude if you have lung disease (asthma, emphysema, etc.) or heart disease (angina, heart failure, or bad valves).

Smokers should put on oxygen on the ground, and will be well served by wearing it above about 5000 ft. Yes, I know it doesn't feel like the manly thing, but you'll do fewer stupid, embarrassing things in the aircraft. Count on it.

Similarly, tow pilots who go soaring after flying tows should put on oxygen on the ground, as well.

If you have anemia, or any heart or lung disease, it would be a safe thing to talk specifically about your own altitude tolerance with a lung specialist, and devise with advice a safe personal maximum altitude and rates of oxygen flow with altitude.

For more information, Google any of the key phrases that are in quotes in this article. A good site on altitude physiology is www.altitude.org, focused on mountain climbing – click on "High Altitude." Another is Patrick Nelligan's tutorial for anesthesia, http://www.ccmtutorials.com/rs/oxygen/.