UNDERSTANDING A DIVE COMPUTER

by S. Angelini, Ph.D.

Mares S.p.A.

The decompression algorithm in a dive computer is an attempt to replicate the effects of a dive on the human body using mathematical formulas. The on-take and release of nitrogen is simulated using a certain number of so-called compartments, each of which represents a tissue group in the body. So for instance we have a compartment representing the muscles, one representing the bones etc.

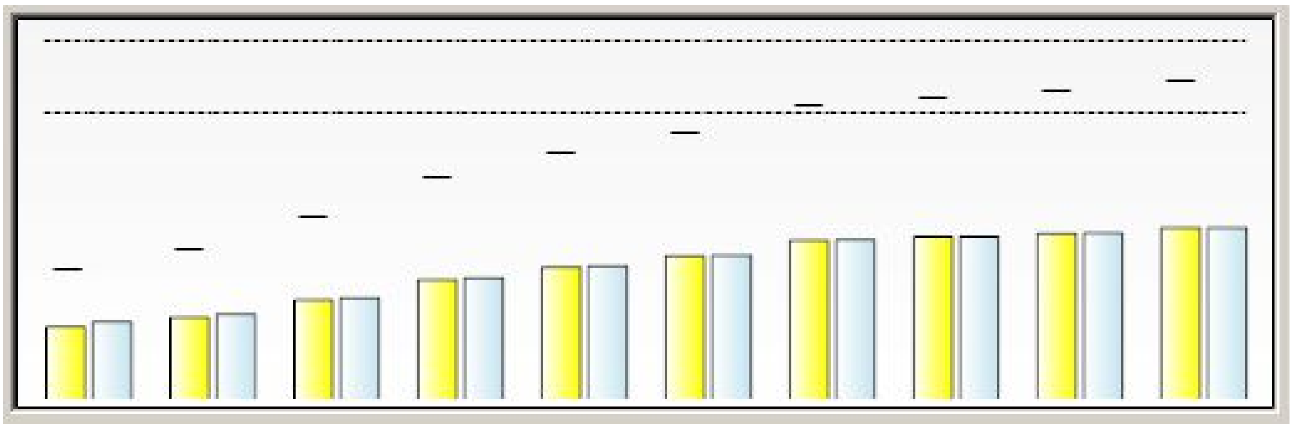
The tissues are identified by their half time[1], a parameter indicative of the speed at which it takes on nitrogen. The Mares algorithm utilizes ten tissues, with the following half times in minutes: 2.5, 5, 10, 20, 30, 40, 60, 80, 120 and 240. Tissues with short half times are called "fast", tissues with long half times are called "slow".

Each tissue is also identified by a second parameter, the so-called M value[2]. This represents the ratio of the maximum amount of pressure with respect to ambient pressure which a given tissue can tolerate. The term used to describe excess pressure in a tissue with respect to ambient pressure is "supersaturation".

In essence, a dive computer tracks the ongassing and offgassing of nitrogen in each tissue, based on the time-depth profile and the half time of each tissue. **The control criterion for a safe ascent is that no tissue exceeds the M value during the dive or upon surfacing.**

The evolution of the pressure, or tension, in each tissue is described in a dedicated screen of Dive Organizer. The ten tissues are presented on a horizontal axis, with the half times increasing from left to right.

Each tissue is represented with two vertical bars. The height of the left bar represents the instantaneous load calculated at any given moment in time.



The height of the right bar reflects the projected value after an ascent to the surface at 10m/33ft per minute from the current depth. This is very important because during an ascent nitrogen is still being

---

1 The name stems from the definition that within this time, a tissue will reduce the difference from its initial state to the new condition by half. Within two half times a tissue reduces the gap by 75% (50% of the remaining 50% in the second half time), by 87.5 in three half times, 93.75% in 4 half times, 96.875% in 5 half times and 98.44% in 6 half times.

2 In the Mares RGBM algorithm, M values are dynamic and adapt themselves to the profile.

exchanged and this must be accounted for (this is quite obvious when one considers that an ascent from 40m/130ft lasts at least 4 minutes, almost twice the half time of the fastest tissue and almost a full half time of the second fastest tissue).

Depending on the status of the tissue at a given time, the bar to the left can be a little bit higher or a little bit lower than the bar to the right. It is higher if the tissue is rather full of nitrogen and during the ascent is going to offgas due to the diminishing pressure. It is lower if the tissue is still rather empty and in spite of the diminishing pressure encountered during the ascent, will ongas more than it will offgas (obviously, every tissue will offgas if near enough to the surface).

Note that, for the slow tissues to the far right, due to the long half times, the difference during an ascent is imperceptible and the two bars representative of a tissue have the same height.

We normalize the vertical axis so that for each tissue the M value is 100, and then draw a horizontal line at 100 (labeled “0”), at 130 (labeled “3m”) and at 160 (labeled “6m”). If any of the right bars crosses the 0 line during the dive, it means that we have incurred a decompression obligation, because we would have exceeded the maximum tolerated supersaturation upon reaching the surface. For easier graphic interpretation, the bar then turns from BLUE to RED. Similarly, any right bar crossing the 3m line means that we have incurred a 6m/20ft obligation, because we would have exceeded the maximum tolerated supersaturation upon reaching a depth of 3m/10ft. Note that *a 6m/20ft stop does not mean that we have to stop at 6m, rather it means that we cannot go as shallow as 3m/10ft*. The usage of the 3m/10ft discretization thus implies that if our nitrogen load is incompatible with the ambient pressure at 3m/10ft, we have to stop at 6m/20ft until we offgas enough nitrogen to become compatible with the ambient pressure at 3m/10ft. This line of reasoning can be extended also to a 9m/30ft stop and beyond, but we limit our representation to these two lines in order not to overcrowd the graph.

Since the M values are not the same for each tissue (faster tissues tolerate more supersaturation than slower tissues), and since all tissues start the first dive with 0.79 atm of partial pressure of nitrogen (saturation breathing air at atmospheric conditions at sea level[3]), it results that at the beginning of a first dive the tissues to the left are lower than the tissues to the right (their height being 100 divided by the corresponding M value). We use the term “first dive” to refer to a non-repetitive dive, so that there is no residual nitrogen from a previous dive to alter the landscape. Everything described in the following applies to repetitive dives as well, of course, with the only difference that the starting point is not with all tissues at 0.79 atm of ppN2 but at a higher level, accounting for what remained from the previous dive and interceding surface interval. Graphically, however, we understand why a repetitive dive is more restrictive than a non-repetitive dive: if there is nitrogen left over from a previous dive, each bar will be closer to the 0 line at the beginning of the dive and hence there is less time available before one of them crosses the limit.

Corresponding to each tissue, the graph presents also a small horizontal segment, superposed to the left bar of each tissue. The position of this segment along the vertical axis represents the partial pressure of nitrogen in the inhaled gas. During a dive you will see this segment move up and down with increasing/decreasing depth. In case of a gas switch, say from air to 50% nitrox, there will be a sharp jump in the position of this segment.

---

[3] For dives in high altitude mountain lakes the atmospheric pressure is lower than at sea level, and this is automatically adjusted for in the dive computer. M-values for such dives change as well, and have to be adjusted manually by selecting the corresponding altitude class in the dive computer.

The position of this segment along the vertical axis plays an important role in understanding the tissue dynamics, since the distance between it and the top of the bar represents the difference in nitrogen partial pressure in the tissue and in the inhaled gas, i.e. the driving force of the gas exchange. This is also called pressure gradient. If the two are far apart, there is strong ongassing or offgassing (within the limitations of the half time). If the two are close, the tissue is almost in equilibrium. Note that, for easier interpretation of the graph, when the segment is ABOVE the bar and thus the tissue is taking on gas (partial pressure of inhaled gas is higher than the partial pressure in the tissue) the bar itself is YELLOW; when the segment is INSIDE the bar and thus the tissue is offgassing (partial pressure of inhaled gas is lower than the partial pressure in the tissue) the bar itself is GREEN.

Interpretation of a square dive

We utilize a square dive to 30m/100ft for 30min because conceptually it is the easiest profile to describe the various aspects presented above. The profile is depicted in figure 1, and here we also see the tissue load at the very beginning of the dive. The lower horizontal line is the M value, and the height of each bar is referenced to it. Since the M values decrease as the half times increase, the height of the bars increase from left to right. We see that the small segment representing the partial pressure of the inhaled gas is aligned with the top of each bar (saturation at atmospheric conditions). In case of a nitrox dive, the segment would be inside the bar, indicative of the fact that breathing nitrox on the surface would lead to initial offgassing.

Fig. 1: Beginning of dive.

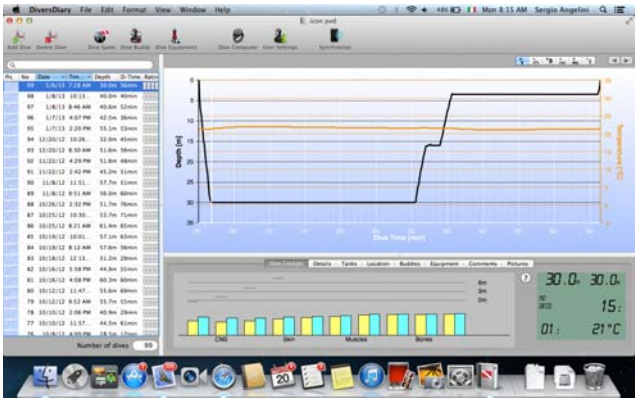


Fig. 2: End of descent

In figure 2 we see the situation at the end of the descent: the bars have grown slightly in height as nitrogen has been absorbed over the minute and a half long descent. We can see also that the segments representing the nitrogen pressure in the inhaled gas have travelled upwards, indicative that gas is being forced into the tissues at a speed proportional to the distance between each segment and the top of each bar.

At constant depth, the speed at which a tissue ongasses diminishes over time, as the difference in pressures between inhaled gas and tissue tension decreases. This can be seen graphically because the segment symbolizing the inhaled nitrogen pressure does not move (since the depth is constant) while the bar increases as nitrogen is absorbed, so the two get closer. If one stays long enough at a constant depth, the tissue will reach the segment[4] and no gas transfer takes place any longer: the tissue is said to be

[4] Pressure equality is reached asymptotically, but in practical terms we can consider this to happen within 6 half times.

saturated. In figure 5 further below we can see that after 30 minutes at 30m, indeed the 2.5 and 5 minutes tissues are saturated, while the slower tissues are farther away from pressure equality the longer the tissue half time.

In figure 3 we see the situation at minute 18, just prior to the end of the no deco limits: we can see that the fastest tissue is practically saturated (the segment and the top of the bar coincide) whereas the very slow tissues have grown only very little. But what stands out most in this instance is the fact that the right bar of the third segment is about to touch the horizontal line. Indeed, at the very next time step, show in figure 4, it will cross this limit.

Fig. 3: End of no deco limit.

Fig. 4: Beginning of deco dive.

Here in figure 4 the third tissue has reached the limit of the horizontal line. As discussed above, this signifies that this tissue, if taken to the surface at 10m/min, will be in violation of the control criterion and **hence this is the beginning of the decompression obligation**. For easy graphic interpretation, the bar itself turns from blue to red. What is also interesting is that the left bar of the second tissue is also over the limit, but this tissue would offgass enough during a normal ascent not to violate the control criterion.

Let’s now take a look at the end of the 30m/100ft section, here in figure 5: we see that the control criterion is violated by 5 segments. Curiously, the first two tissues, now both saturated at 4atm absolute pressure, will offgas enough during ascent not to ever violate the control criterion. In other words, for dives up to 30m the first two tissues are never going to be the limiting factor. We also see that a depth decrease of 0.3m/1ft is sufficient to make the first tissue switch over to offgassing, which makes sense since it was saturated at 30m and any decrease in pressure will bring the little segment underneath the top of the bar.

Fig. 5: Tissue status upon beginning of ascent.

Fig. 6: Tissue status during deep stop.

Let’s now ascend to the depth of the deep stop, figure 7: we see that the first four tissues are offgassing under an appreciable gradient (distance from the top of the bar to the horizontal segment). The fifth bar is still ongassing, but at a very reduced gradient. Only from the 6th tissue onward is there still considerable gradient for ongassing. This is the 40 minute tissue, so a two-minute deep stop here will hardly affect the status of its tension. The 2 minutes however will allow the fast (and sensitive tissues) to get rid of a good amount of gas while the ambient pressure is relatively high, thus controlling microbubble growth. So we see how for this profile, though from a purely theoretical point of view, a deep stop can be seen as advantageous during an ascent.

We now proceed to the depth of the deco stop, figure 8, and see that all but the slowest tissue are offgassing, and still 5 of them are violating the control criterion.

Fig. 7: Tissue tension at beginning of deco stop.

Figure 8: Tissue tension at the end of deco stop.

In figure 9 we see the situation at the end of the decompression obligation: all blue bars are now below the limit line. However, there is no margin of safety, the bars are barely satisfying the criterion for a safe ascent. This is why it is suggested to always perform a 3-5 minute safety stop at 3-5m/10-15ft.

The next figures depict the situation during a real dive with a gas switch. In particular, they show the tissue situation just before and just after the gas switch. It is quite obvious why using a high O2 deco mix is so advantageous! The partial pressure of nitrogen in the inhaled gas drops significantly, and not only are two more tissues offgassing rather than ongassing, but the pressure gradients for offgassing have increased significantly in the tissues that were already offgassing.

Fig. 9: Tissue status just prior to a gas switch.

Fig. 10: Tissue status just after a gas switch.

Note that in this dive we also have a 6m/20ft obligation, and graphically this is represented by some of the right bars having crossed the 3m horizontal line.

For the same dive, figures 11 through 13 below show the tissue status at the end of mandatory decompression and then 5 and 16 minutes later. The bars decrease further and the farther the bars from the lower horizontal line, the safer the dive. But since the speed of offgassing diminishes as the gas itself is released, the highest gain is towards the beginning of the safety stop and becomes less and less efficient as the duration is extended. Basically, the purpose of a safety stop is to reduce the tissue load beyond the minimum requirement (M value) and this is done quite efficiently with a 5 minute stop at 3-5m/10-15ft depth.

Fig. 11: Tissue status at end of deco obligation.

Fig. 12: Tissue status 5 minutes beyond end of deco.

Fig. 13: Tissue status after 16 minutes at 3m beyond the end of decompression obligation.

So whereas one may surface as soon as the deco obligation is elapsed, one may want to add a safety stop to put some distance between the bars and the 0 line. The first minutes are the most efficient ones for gas exchange, having the highest gradients, whereas the longer one stays the less efficient the safety stop becomes.