UNDERSTANDING A DIVE COMPUTER

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• UNDERSTANDING A DIVE COMPUTER

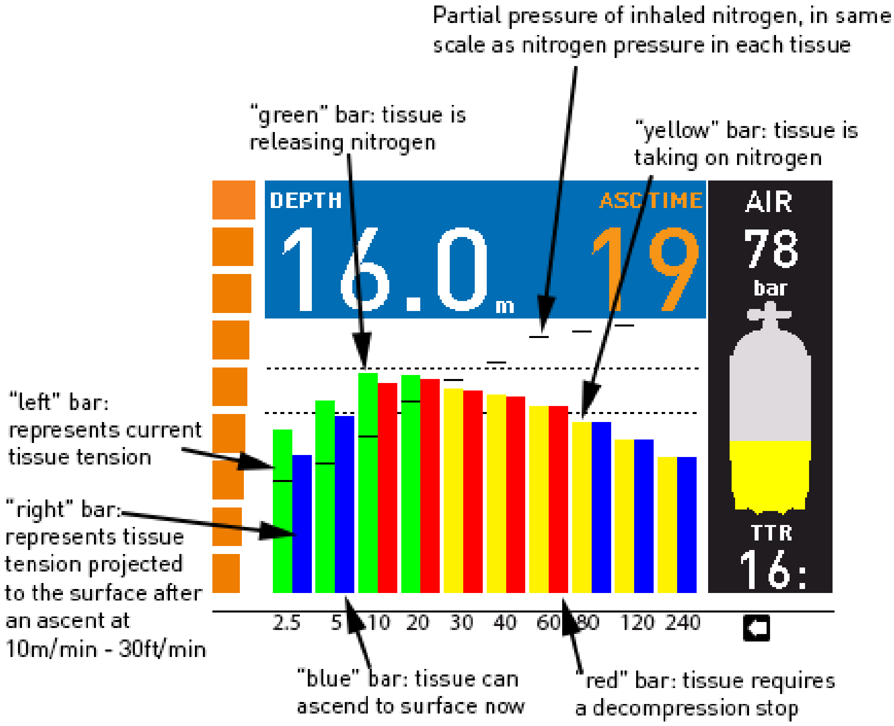
The decompression algorithm in a dive computer is an attempt to replicate the effects of a dive on the human body using mathematical formulas. The on-take and release of nitrogen are simulated using a certain number of so-called compartments, each of which represents a tissue group in the body. So for 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 (also called tension) 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.** If the criterion is not met, then the ascent is interrupted by one or more decompression stops during which nitrogen can be offgassed while the diver is at an ambient pressure at which the control criterion is met.

In this document we describe how nitrogen pressure (also referred to as tissue tension) evolves during a dive and how it affects the decompression calculation. For this purpose we use the new tissue graph feature in Icon HD Net Ready Firmware 4.0, which allows following the evolution of the tension in each tissue "live" during the dive. The same tissue tension evolution can be viewed in retrospect on a PC or Mac, (using DiveOrganizer or DivesDiary, respectively) after having downloaded any compatible Mares dive computer.



The ten tissues are presented on a horizontal axis, with the half times increasing from left to right. Each tissue is represented by 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 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 left bar can be a little bit higher or a little bit lower than the right bar. 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.

The vertical axis of the graph is normalized so that for each tissue the M value is at the same height. We then draw a horizontal line across the graph at this value. We call this line the "zero" line, as in 0m, i.e. surface. It allows a quick visual check: if any of the right bars crosses this line during the dive, it means that if we were to ascend to the surface right now the corresponding tissue would violate the control criterion (it would have exceeded the M value). Consequently this implies that we have incurred a decompression obligation, i.e. we need to spend some time below the surface (at higher than surface ambient pressure at which the control criterion is still met) where we can offgas some nitrogen in order to reduce the height of the bar until it drops again below the zero line. To make the graph more immediately understandable, the right bars turn from BLUE to RED when it crosses the zero line. Hence a RED right bar is indicative of a mandatory decompression stop. When enough nitrogen has been released for the bar to drop again underneath the zero line, its color reverts to blue.

The graph features a second horizontal line, above the zero line, which we call the "3m/10ft" line. It represents the control criterion applied to a depth of 3m/10ft. Similarly to what we have seen regarding the zero line, any right bar that crosses this line implies that if we were to ascend now, we would be in violation of the control criterion already at 3m/10ft. In other words, as soon as a right bar crosses this line we have incurred a 6m/20ft decompression obligation[3]. This line of reasoning can be extended also to a 9m/30ft stop and beyond, but we limit our

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.

3 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, as much as a 3m/10ft stop does not mean that we have to stop at 3m/10 but rather that we cannot ascend directly to the surface. The usage of 3m/10ft increments in defining the decompression stops 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.

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 (tissues in equilibrium with air at atmospheric conditions at sea level[4]), it results that at the beginning of a first dive the tissues to the left are lower than the tissues to the right[5]. 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 ppN_2 but at a higher level, accounting for what remained from the previous dive and interceding surface interval. Graphically, however, it becomes obvious 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 zero line at the beginning of the dive and hence for any given depth 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 80% nitrox, there will be a sharp jump in the position of this segment.

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.

• APPLICATION OF THE TISSUE GRAPH TO 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. We analyze the saturation status of all tissues in 9 particular instances of the dive. For this we use the graphics as provided by Icon HD during the dive itself. We start with the situation at the very beginning of the dive, depicted in Figure 1. We see that all tissues are well below the zero line and we also see that the small segment representing the partial pressure of the inhaled gas is aligned with the top of each bar (equilibrium 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.

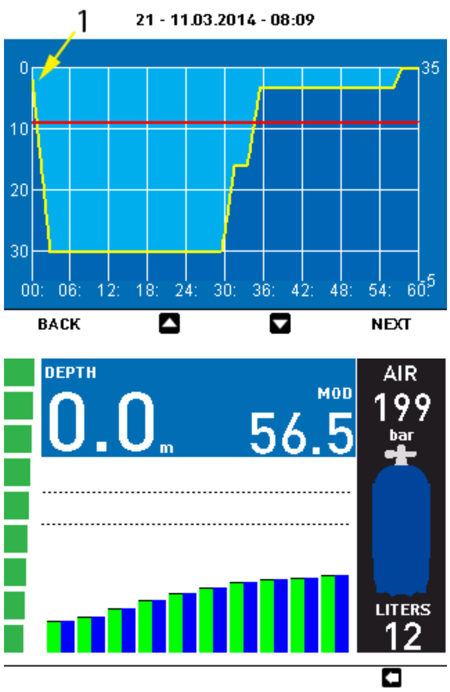


Fig. 1: Tissue tension at beginning of dive.

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.

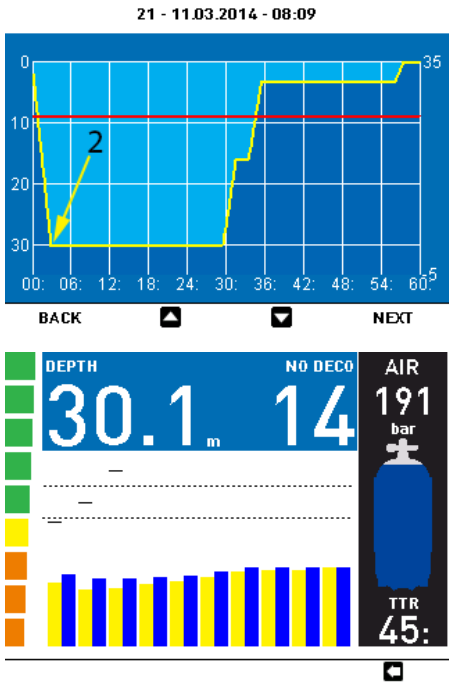


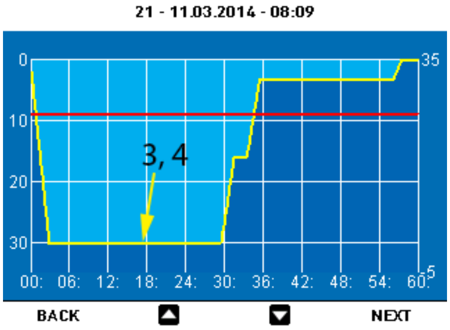
Fig. 2: Tissue tension at end of descent.

At constant depth, the speed at which a tissue ongasses diminishes over time, as the difference in pressures between inhaled gas and tissue saturation 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[6] and no gas transfer takes place any longer: the tissue is said to be in equilibrium (or 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.

[4] 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.

[5] Since the position of the M value along the vertical axis was set to be the same for all tissues, the initial height for the bars for each tissue is the height of the zero line divided by the M value of the tissue itself.



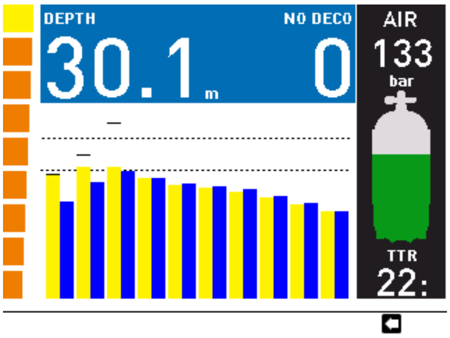
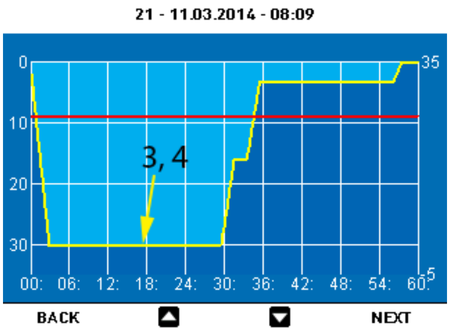


Fig. 3: Tissue tension at end of no deco limit.

In Figure 4 the third tissue has crossed the zero 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.



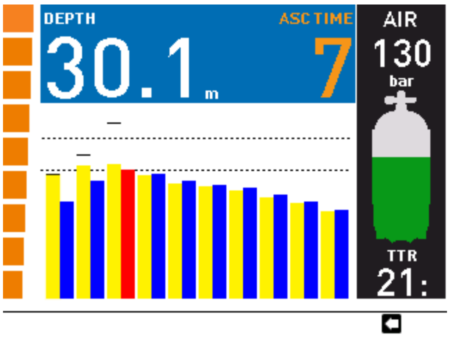
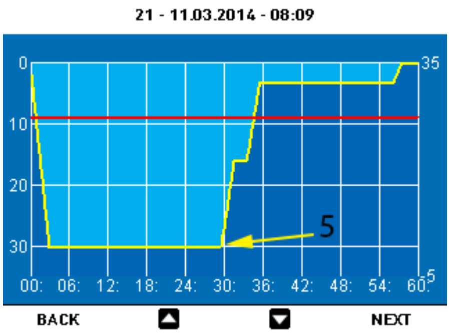


Fig. 4: Tissue tension at beginning of a decompression obligation.

Let's now take a look at the end of the 30m/100ft section 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 0.5m/2ft is sufficient to make the first two tissues switch over to offgassing, which makes sense since they were saturated at 30m and any decrease in pressure will bring the little segment underneath the top of the bar.



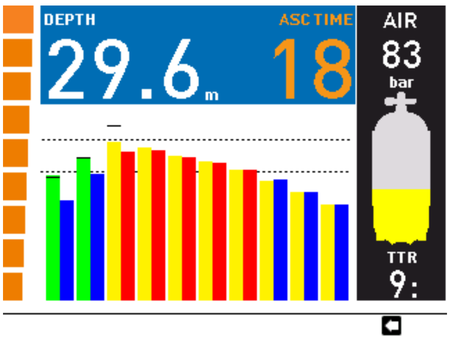
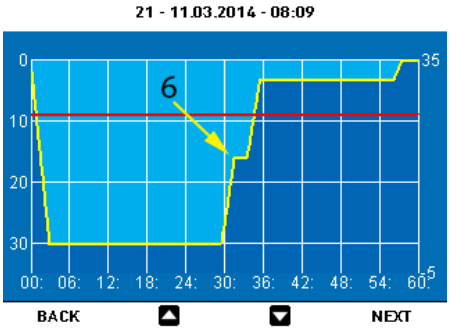


Fig. 5: Tissue tension upon beginning of ascent.

Let's now ascend to the depth of the deep stop, Figure 6: 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 saturation. 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.



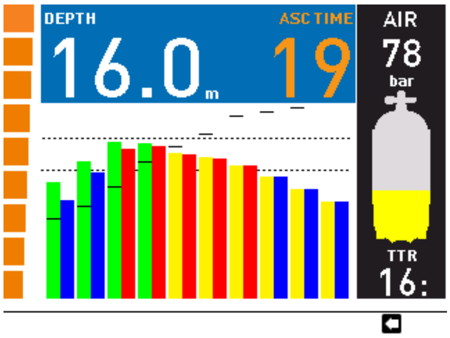


Fig. 6: Tissue tension at beginning of deep stop.

From the point of view of the algorithm, for this profile a deep stop can thus be seen as advantageous during an ascent. This can be inferred from Figure 7, showing the tissue saturation at the end of the deep stop: the green bars have drop markedly while hardly anything has changed in the yellow bars.

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

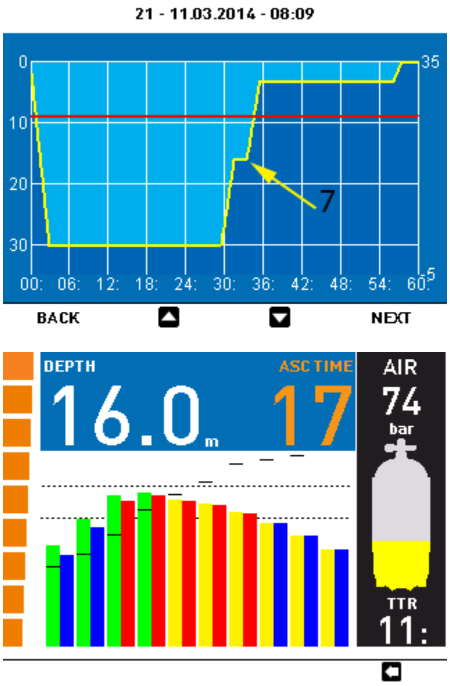


Fig. 7: Tissue tension at end of deep stop.

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.

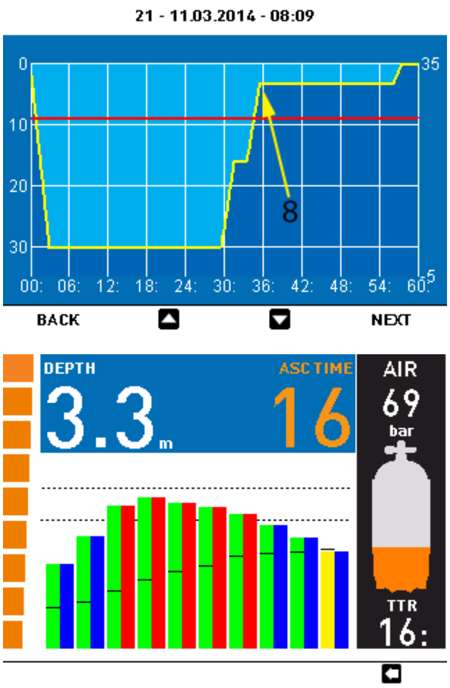


Fig. 8: Tissue tension at beginning of deco stop.

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 a good idea to always perform a 3-5 minute safety stop at 3-5m/10-15ft, even after at the end of a decompression dive.

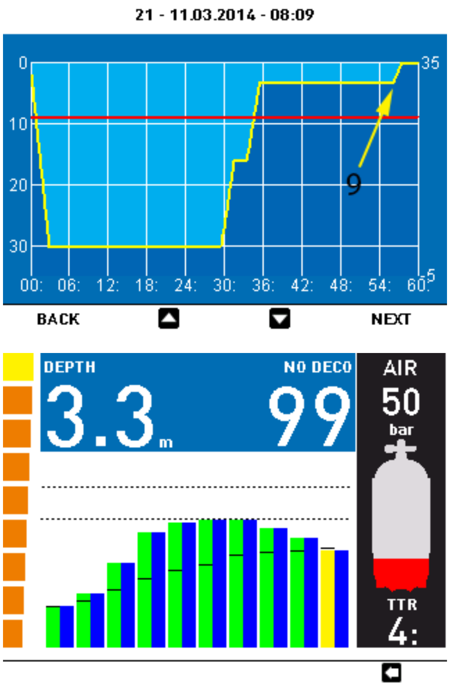


Fig. 9: Tissue tension at the end of deco stop.

• APPLICATION OF THE TISSUE GRAPH TO AN ACTUAL DIVE PROFILE INCLUDING A SWITCH TO A HIGH-OXYGEN-CONTENT DECOMPRESSION GAS.

Figures 10 and 11 depict the situation during a real dive in which a gas switch from air to 80% nitrox was performed. In particular, they show the tissue tension 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.

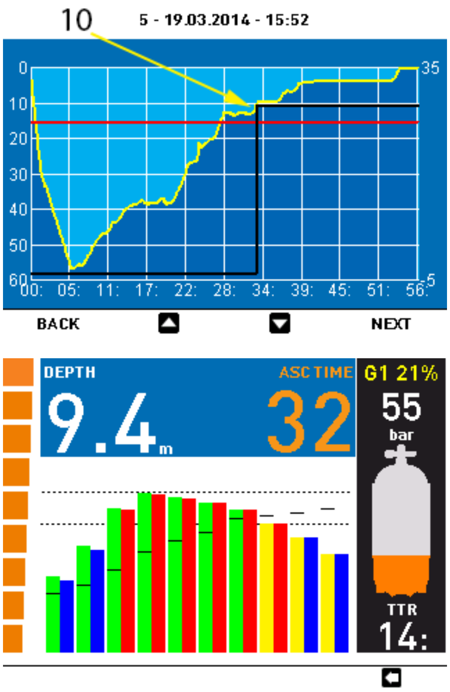


Fig. 10: Tissue tension just before a gas switch.

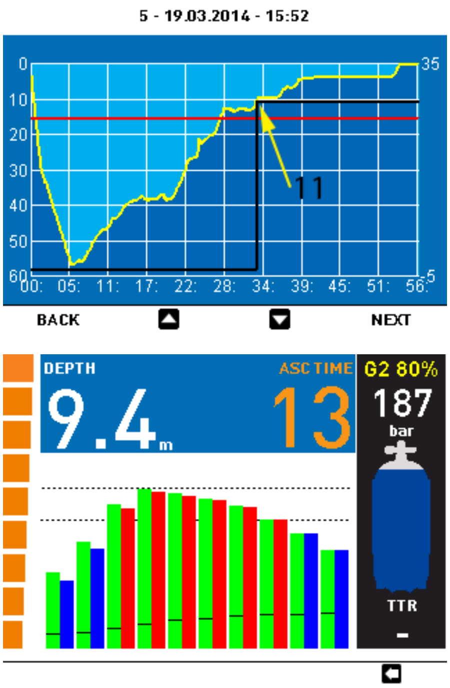


Fig. 11: Tissue tension just after a gas switch.

For the same dive, Figure 12 shows the tissue saturation at the end of mandatory decompression and Figure 13 shows the tissue saturation 5 minutes later. The bars decrease further and the farther the bars from the lower horizontal line, the safer the dive.

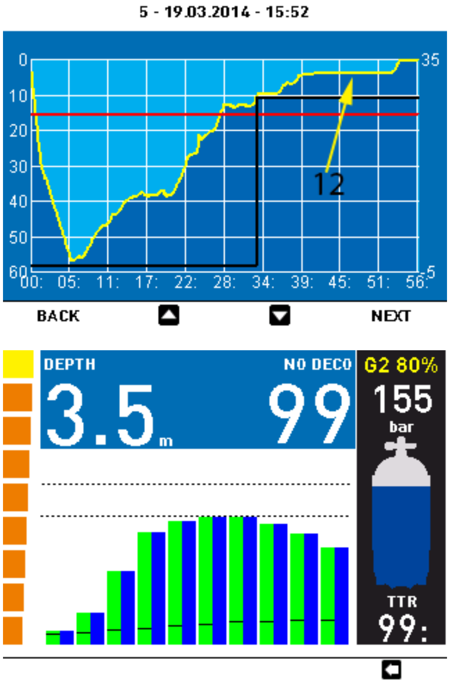


Fig. 12: Tissue saturation at end of deco obligation.

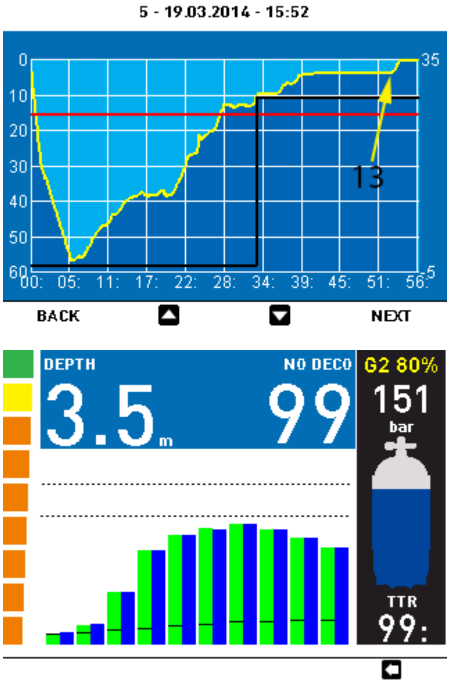


Fig. 13: Tissue saturation 5 minutes beyond end of the decompression obligation.