Suunto
Reduced Gradient
Bubble Model

SUUNTO
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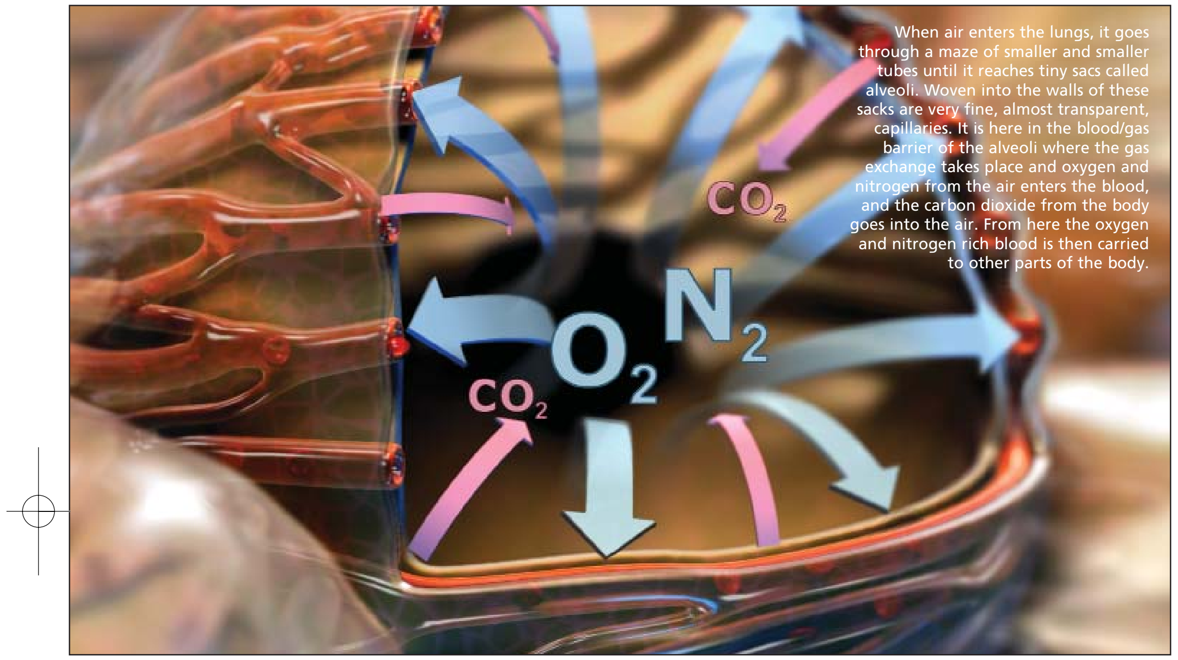
THE CAUSES OF DECOMPRESSION ILLNESS

Air consists roughly of 78% Nitrogen (N_2), 21% Oxygen (O_2) and 1% Argon (Ar), Carbon Dioxide (CO_2) and other trace gases. When we scuba dive, we metabolise the oxygen, but nitrogen being an inert gas, is stored in the body just like the unseen gas in an unopened bottle of soda water.



When air enters the lungs, it goes through a maze of smaller and smaller tubes until it reaches tiny sacs called alveoli. Woven into the walls of these sacks are very fine, almost transparent, capillaries. It is here in the blood/gas barrier of the alveoli where the gas exchange takes place and oxygen and nitrogen from the air enters the blood, and the carbon dioxide from the body goes into the air. From here the oxygen and nitrogen rich blood is then carried to other parts of the body.

It all starts in the lungs, where the nitrogen is first diffused through the alveolar and capillary membranes, into solution in the blood.

This nitrogen rich blood is then distributed by the arteries to the various tissues, throughout the body. This is referred to as on-gassing. In decompression modelling, these tissues are commonly called compartments. The deeper and longer we dive; the more nitrogen is taken up by the body until a tissue finally reaches a point of saturation.

During a dive, tissues saturate with nitrogen at different rates. This is determined by the blood flow rate to the tissue in question. The brain, for example, has a very good blood supply, and is classified as a "fast" tissue, whilst joints typically have a poor blood supply and are rated as "slow" tissue. There are several others in between.

The length of time that it takes for a tissue to reach a 50% saturation level at depth is called the tissue half time and it is usually measured in minutes.

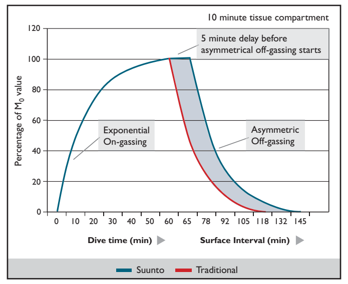
During ascent the process is reversed, and the gas is off-loaded from the tissues back into the venous blood supply. This blood is then returned via the heart to the lungs where the excess N_2 and CO_2 diffuses out through the alveoli in the lungs, and is exhaled.

This process is known as off-gassing. The determining factor as to the extent to which a tissue off-gases is the pressure gradient (the difference between the tissue gas tension and the ambient pressure). There is a further important factor called the "oxygen window".

This is a naturally occurring gas tension reduction that arises in the actual tissues and venous circulation compared to the lungs and arterial circulation. This leaves room for the expanding gas, caused by the ascent, to go without exceeding the ambient pressure provided a suitable ascent rate is not exceeded. Suunto's designed ascent rate of 10m/minute takes full advantage of this phenomenon.

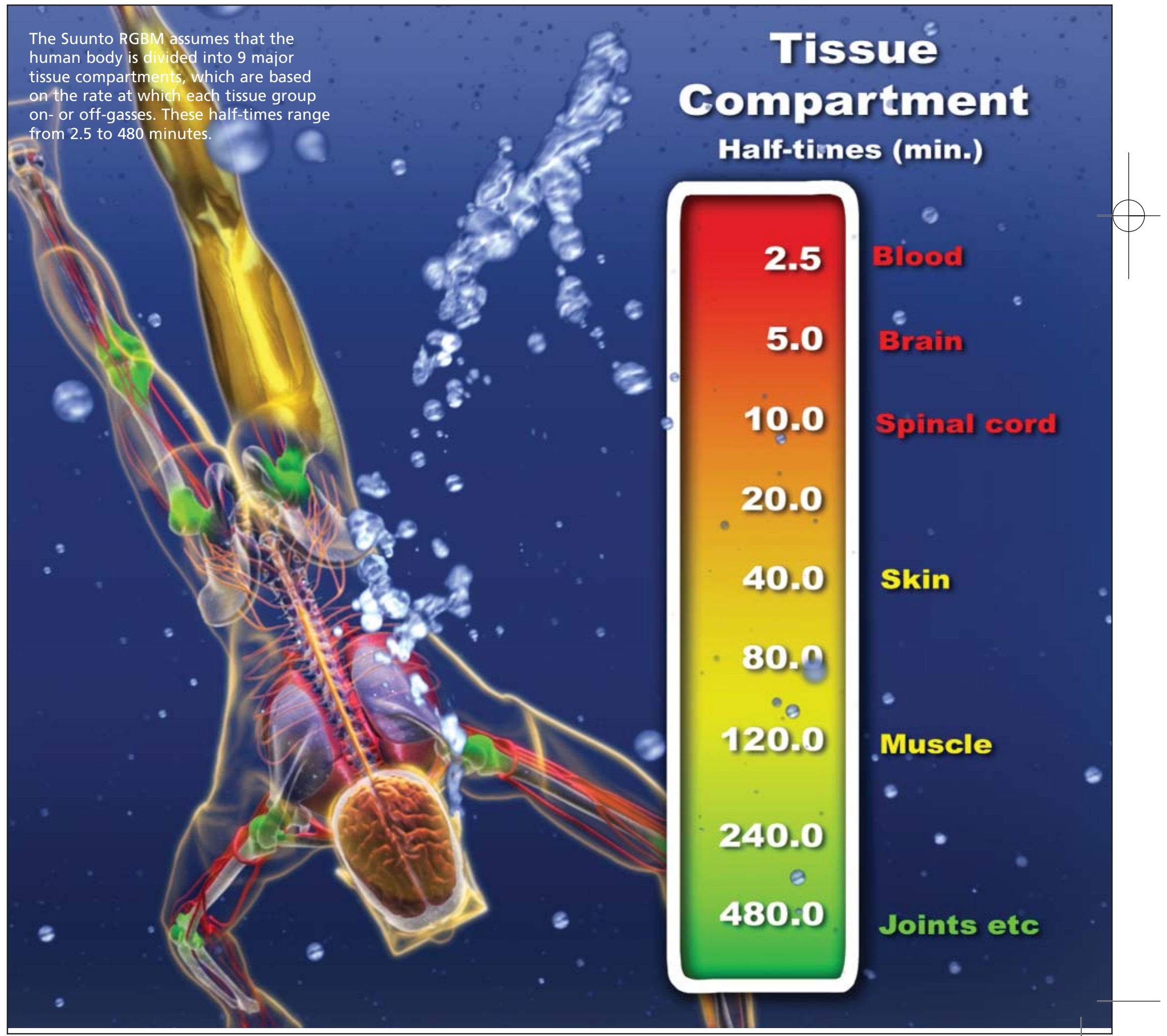
The potential for decompression illness occurs when the ambient pressure reduction during ascent is too rapid, and some of the excess nitrogen in the body is released from solution to form bubbles. These bubbles may then interfere with normal body functions, restricting blood flow and causing damage to tissues and nerves.

For a diver with decompression illness, the symptoms may commence while still underwater or it may take several hours after surfacing. In some cases the symptoms may not show for several days.



The Suunto RGBM uses an exponential form for calculating the uptake of nitrogen. However, because of the influence of microbubbles, which tend to restrict nitrogen out-gassing, an asymmetrical nitrogen elimination curve, as determined by Dr Merrill Spencer, is used. This system better protects the diver from decompression illness (DCI) and is the first in a series of microbubble protective measures used in Suunto RGBM. Additionally there is an 5 minute extra delay on the surface before off-gassing starts.

In this illustration we can see a cross-section of a capillary delivering blood to muscle tissue. Friction between the muscle cells create micronuclei which attract dissolved gas from the surrounding tissue, forming microbubbles. The microbubbles disturb the blood flow and slow the gas elimination process. Microbubbles are present after almost any kind of dive, but are normally filtered out by the lungs before creating problems. If however they are allowed to grow, they may form DCI bubbles causing decompression illness.



The Suunto RGBM assumes that the human body is divided into 9 major tissue compartments, which are based on the rate at which each tissue group on- or off-gasses. These half-times range from 2.5 to 480 minutes.

INSTRUCTORS RISK LONG TERM DAMAGE, WITH NO SHORT TERM SYMPTOMS

The science of decompression has been a continuously evolving process with the fundamental causes of decompression illness established as early as 1908. In the 1970s the development of Doppler technology allowed researchers to measure the existence of bubbles in the diver's body. The Doppler devices did this by reading an ultrasonic signal that was reflected back from the bubbles in the test subject. When the reflected signal was received by the Doppler recording device it emitted a chirping sound. The number of chirps indicated the number of bubbles. It was discovered that small bubbles, microbubbles, were present after almost every dive, although the divers had no actual symptoms of decompression illness.

Until recently, little has been known about the behaviour of microbubbles, other than the fact that their existence has been proven by Doppler measurement.

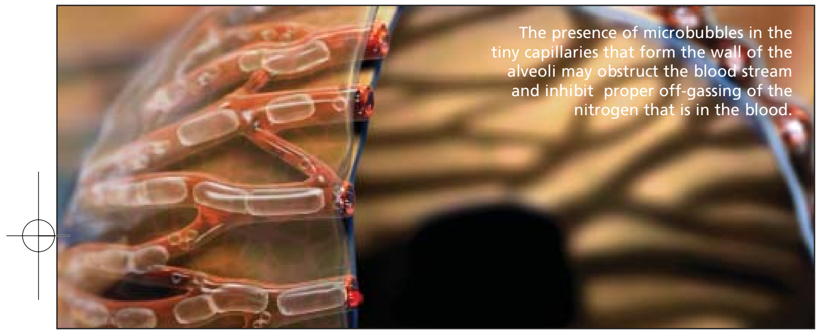
What has also been established is that once formed, these bubbles are unstable. They have an ability to attract dissolved gas from surrounding tissues and the likelihood of a bubble either expanding or collapsing, is determined by a range of factors. These factors include the surface tension that exists on the bubble's surface, the pressure within the bubble and the ambient pressure relative to the bubble.

It is known that a diver, who completes multiple dives within a given day or even over a number of days, may present with a build-up of these microbubbles. And a repetitive diver, who unknowingly has already accumulated microbubbles, may have a higher predisposition to decompression illness. It is also known that they can cause longer-term problems such as neurological damage.

This is particularly relevant to professional divers such as instructors, who complete a large amount of repetitive diving, often with many ascents in one training session.

Also, microbubbles are known to accumulate inside the alveoli, obstructing and slowing down the off-gassing.

Additionally, given the right circumstances, microbubbles can grow to form real DCI bubbles, which are out-of-control microbubbles that have grown too large. It has been recognised that microbubbles needed to be controlled, and some dive computer manufacturers have made their computers more conservative, to accommodate microbubble formation. The Suunto solution to microbubble control is based on measuring a number of factors that correlate to microbubble formation, growth and decay depending on diving behaviour. These factors are then used to adjust the tissue limits of the basic decompression model in real time, based on the actual diving profiles. If needed, prolonged safety stops are introduced and/or a longer surface interval prompted.


The presence of microbubbles in the tiny capillaries that form the wall of the alveoli may obstruct the blood stream and inhibit proper off-gassing of the nitrogen that is in the blood.

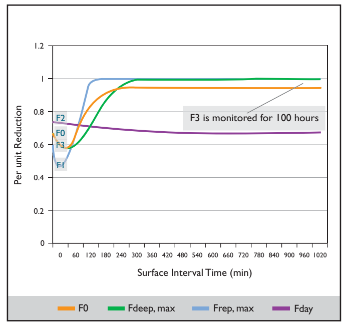
SUUNTO RGBM CONTROLS MICROBUBBLES

More recently, the availability of electron scanning microscopes has allowed researchers to actually see micronuclei, which are the bubble seeds that precede microbubble formation. These micronuclei are only a few microns in diameter.

This has now given researchers deeper insight into the formation and behaviour of microbubbles. It is in the understanding of the formation and dynamics of these microbubbles, how to suppress and control them that has led the most recent research by the Suunto technical team.

The breakthrough is that the Suunto Reduced Gradient Bubble Model controls the behaviour of microbubbles, before they become DCI bubbles.

Divers who properly follow the instructions of a dive computer that utilises the Suunto RGBM may experience a reduction in diving incidents, without requiring a more conservative dive time for most dives.

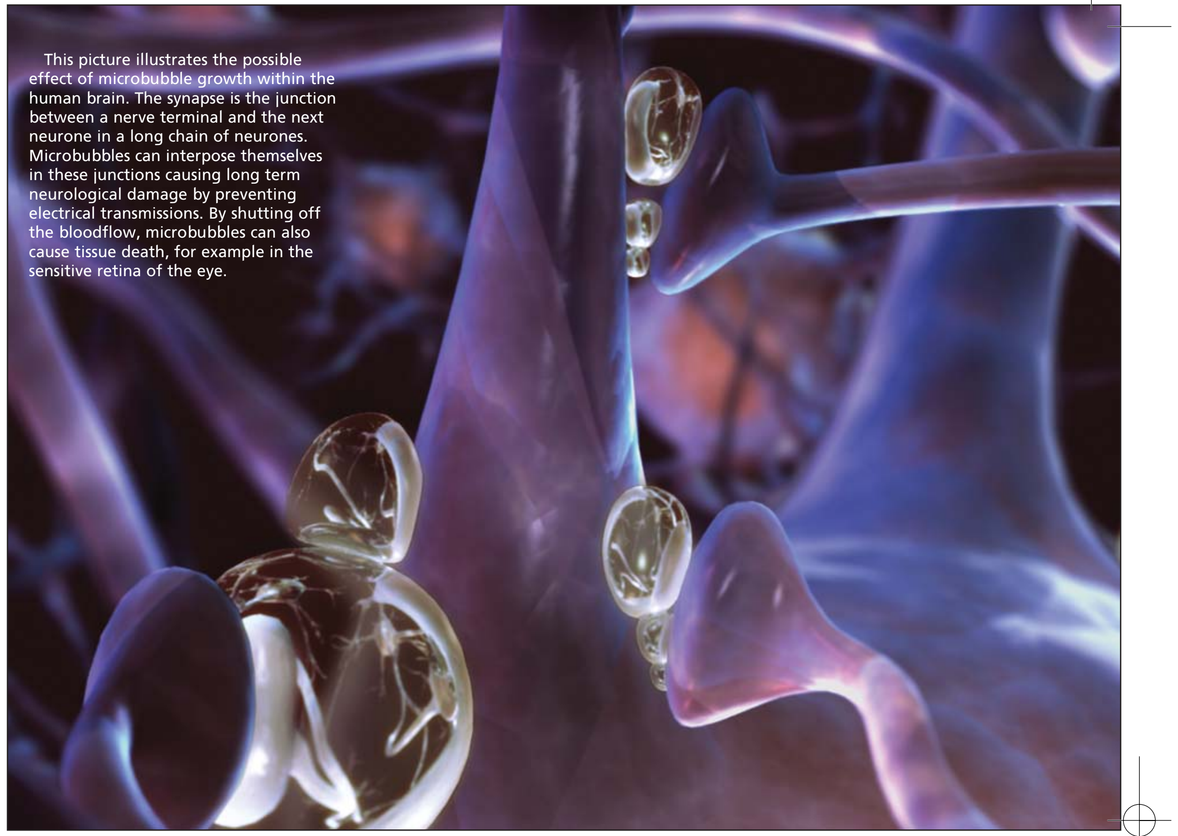


Repetitive dives - F1 - Microbubbles mainly occur in the venous circulation during the surface intervals between dives. They are washed with the blood to the pulmonary filter (lungs), where they may reduce the surface area and inhibit off-gassing. This effect will continue until the production of microbubbles ceases and the bubbles in the lungs dissipate. This continues for about three hours after surfacing. The Suunto RGBM algorithm calculates correction factors to cope with this issue.

Depth sequence - F2 - In any series of dives, the Suunto RGBM calculates that diving deeper than the previous dive stimulates micro-nuclei into growth. During the surface interval following such an event, the Suunto RGBM recalculates future decompression obligations based upon the depth excess of the last dive compared to the one before it.

Multi-day diving - F3 - Pre-existing micro-nuclei are excited into a higher energy state by diving (compression and decompression). They are thought to return to their normal energy level over time scales of days The Suunto RGBM multi-day factor calculates adjustments for a surface interval period of 100 hours.

The combination of the correction factors is applied to the Suunto RGBM's M-values thus reducing the permitted supersaturation gradient, which adjusts the required decompression obligation.

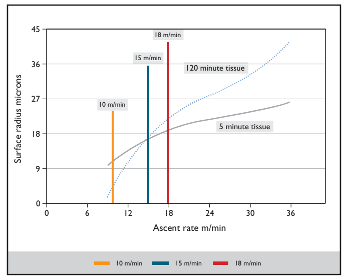

This picture illustrates the possible effect of microbubble growth within the human brain. The synapse is the junction between a nerve terminal and the next neurone in a long chain of neurones. Microbubbles can interpose themselves in these junctions causing long term neurological damage by preventing electrical transmissions. By shutting off the bloodflow, microbubbles can also cause tissue death, for example in the sensitive retina of the eye.

CONTROLLING BUBBLE FORMATION WHILE MAXIMISING OFF-GASSING

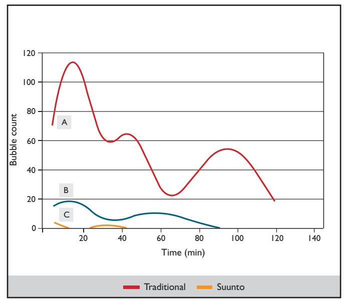
Earlier Haldanian dissolved gas models assumed that in order to decompress, a diver should ascend as quickly as possible to a shallow depth to maximise off-gassing. However, by quickly reaching that shallow depth, the diver may have already formed microbubbles. At the very least, these could potentially obstruct off-gassing and at the worst, may have already caused some tissue damage. Therefore, there is a need to keep the micronuclei from forming into microbubbles and keep any pre-existing microbubbles as small as possible, by applying an appropriate ascent protocol.

If a diver dwells at depth, when microbubbles are very small in size, their high surface tension will help to collapse the bubble down. But there is still the need to maximize the pressure differential as much as possible, to allow tissues to off-gas. This is why the Suunto RGBM considers both factors. For dissolved gas the diver wants to maximize the pressure differential as much as possible, but for any microbubbles, there is the need to keep the pressure high by staying deep. The Suunto RGBM optimises these two contradictory issues by both a combination of a slow ascent rate and continuous decompression curve.

It all comes down to proper control of the expanding nitrogen during an ascent. This is why Suunto has set the maximum ascent rate at 10m/minute.



The effectiveness of a 10m/min ascent rate is clearly demonstrated here with this graph showing how the surface radius of bubbles is significantly reduced by a slower ascent rate. Graph from Basic Decompression Theory and Application by Bruce Weinke, p.56.



This graph shows the effects of "safety stops" on microbubbling. "A" is the bubble count over time after a dive to 36m [120ft] for 25min. "B" is the same with a 2min stop at 3m [10ft]. "C" is still the same but with 1min at 6m [20ft] and 4min at 3m [10ft]. As can be seen bubbling is reduced by a factor of 4-6. Conclusion: free phase (bubble) reduction in pulmonary circulation is impressive when utilizing safety stops. Graph is based on study by Pilmanis A.A 1976: Intravenous Gas Emboli in Man after compressed Air Ocean Diving.

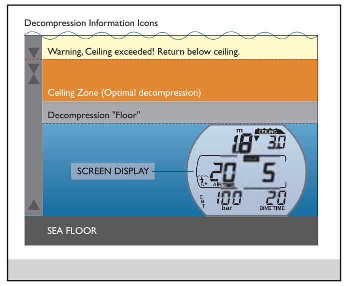
CONTINUOUS DECOMPRESSION OPTIMISES OFF-GASSING AND BUBBLE SUPPRESSION

Traditionally, since Haldane's 1908 tables, decompression stops have always been deployed in fixed steps such as 15m, 12m, 9m, 6m and 3m. This practical method was introduced before the advent of dive computers. However, when ascending, a diver actually decompresses in a series of more gradual mini-steps, effectively creating a smooth decompression curve.

The advent of microprocessors has allowed Suunto to more accurately model the actual decompression behaviour, and a continuous decompression curve been included in the Suunto RGBM's working assumption.

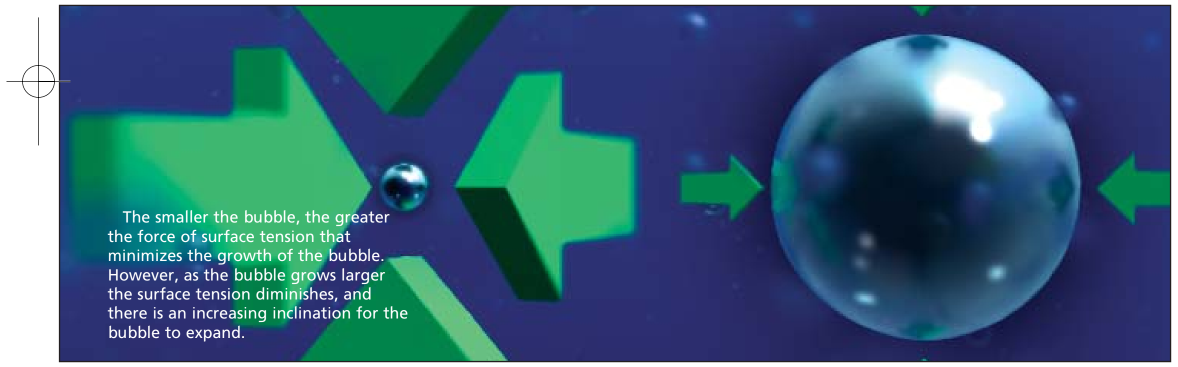
It is known that during the ascent the pressure gradient across the tissues increases. That is the pressure of dissolved gas inside a specific tissue has increased relative to the drop in the ambient pressure. If this gradient is allowed to rise too much, then microbubbling, decompression stress or DCI can occur. During the ascent phase of the dive computer algorithm has the information, which can be used to better control and limit pressure gradients. It is this need to limit pressure gradients, which is the origin of the name Reduced Gradient Bubble Model.

The fundamental idea behind the Suunto RGBM is to maximise the internal pressure of any bubble with respect to tissue tension to dissolve gas out of the bubbles and back into the tissues. This should leave the venous circulation and lungs less restricted by microbubbles, making off-gassing more efficient at the dissolved gas decompression stops.



Suunto dive computers have an unique feature of displaying not only the decompression Ceiling, but also the decompression Floor.

As long as you are below the "Floor", i.e. still on-gassing, an upward arrow is displayed. Once above the floor, the leading tissues start off-gassing, and the upward arrow disappears. The optimal decompression occurs in the Ceiling Zone, which is displayed by both upward and downward arrows. If the ceiling depth is violated a downward pointing arrow and an audible alarm will prompt the diver to descend back to the Ceiling Zone.

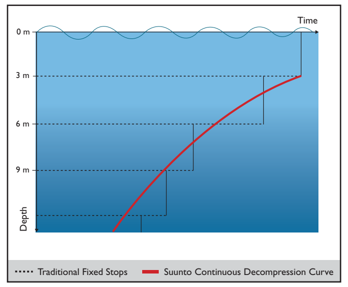


The smaller the bubble, the greater the force of surface tension that minimizes the growth of the bubble. However, as the bubble grows larger the surface tension diminishes, and there is an increasing inclination for the bubble to expand.

During any ascent involving decompression-stops, Suunto dive computers calculate the point at which the leading tissue compartment crosses the ambient pressure line (that is the point at which the tissue's pressure is greater than the ambient pressure), and off-gassing starts. This is referred to as the decompression floor. Above this floor depth and below the ceiling depth is the "decompression zone". The range of the decompression zone, is dependent on the dive profile.

Out-gassing in the leading fast tissues will be slow at or near the floor because the outward gradient is small. Slower tissues may be still on-gassing and given enough time, the decompression obligation may increase, in which case the ceiling may move down and the floor may move up. However, dwelling for a minute or two at the floor before moving up to the decompression ceiling will also help limit microbubble growth, by keeping them compressed. The decompression floor represents the point at which the Suunto RGBM is seeking to maximise bubble compression, while the decompression "ceiling" is maximising off-gassing.

The added advantage of having a decompression ceiling and floor is that it recognises that in rough water, it might be difficult to maintain the exact depth to optimise decompression. However, by maintaining a depth below the ceiling but above the floor, the diver is still decompressing, although slower than optimal, and provides an additional buffer to minimise the risk that waves will not lift the diver above the ceiling. Also, the continuous decompression curve used by Suunto provides a much smoother and a more natural decompression profile than the traditional "step" decompression.



The unique continuous decompression used by Suunto computers provides a smooth and more natural decompression curve compared to traditional predetermined ceiling depths.

If preferred, the diver may still decompress at traditional fixed depths.

PRACTICAL IMPLICATIONS OF THE SUUNTO RGBM

The Suunto Reduced Gradient Bubble Model is a state of the art algorithm for managing both dissolved gas and free-gas in all its stages in the tissues and blood of the diver.

It is a significant advance on the classical Haldane models, which do not predict free-gas (microbubbles).The advantage of Suunto RGBM is a more accurate representation of what is happening in the diver's body, through its ability to adapt to a wide variety of situations.

The Suunto RGBM addresses a number of diving circumstances that have not been considered by previous dissolved gas models, adapting to:

- continuous multiday diving
- closely spaced repetitive dives
- dives deeper than the previous dive
- rapid ascents which produce high microbubble build up

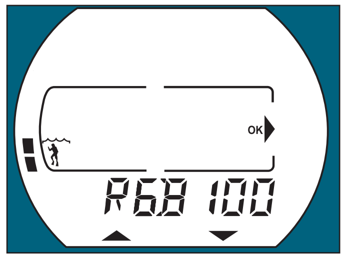
The Suunto RGBM algorithm automatically adapts its predictions of both the effects of microbubble build up and adverse dive profiles in the current dive series. It will further modify these calculations according to the personal adjustment that a diver can select.

Each tissue compartment in the decompression model has a maximum theoretical pressure, called M-value. Depending on the diver's behaviour during the dive and the personal adjustments set, the Suunto RGBM model adjusts the M-values downwards in order to protect the diver from the effects of the generated free-gas.

Depending on circumstances, the adjustments done by the Suunto RGBM may:

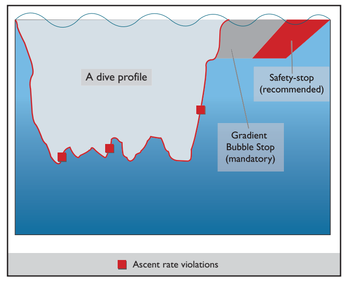
- Add Mandatory Safety stops
- Reduce no-decompression stop times
- Increase decompression stop times
- Advise an extended surface interval

Some diving patterns cumulatively add a higher risk of DCI, such as dives with short surface intervals, repetitive dives deeper than earlier ones, multiple ascents and substantial multiday diving.

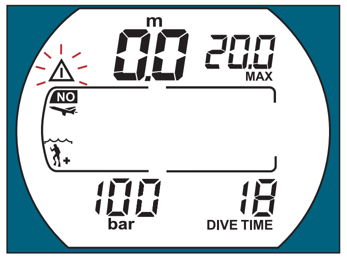


Suunto dive computers allow the diver to personally adjust the dive computer algorithm. Settings include personal, altitude and RGBM factor settings (Suunto Vytec).

The RGBM setting allows experienced divers to choose between the standard RGBM model and an attenuated setting reducing the RGBM effects.



Depending on the conducted dive profile and possible ascent rate violations recommended and mandatory safety stops are added.



If the Suunto RGBM model predicts an excess of microbubble build up after the dive, a flashing warning sign will prompt the diver to extend the surface interval.

SUUNTO'S PERSONAL ADJUSTMENT PROVIDES GREATER ACCURACY

The Suunto RGBM algorithm adapts its predictions of both the effect of microbubble build up and adverse dive profiles in the current series of dives. All Suunto dive computers are shipped with a default setting that provides the full protection of the Suunto RGBM algorithm.

However, some more experienced divers may prefer not to use the full Suunto RGBM model, and therefore, in the Suunto Vytec it is possible to adjust the algorithm to an Attenuated RGBM Model which reduces the effects of the Suunto RGBM model by 50%.

Just as it is possible to reduce the effect of the Suunto RGBM model it is similarly possible to choose gradually more conservative parameters for decompression calculations, when adverse personal conditions exist. The principal personal factors that show a correlation with DCI susceptibility include: physical and dive fitness; age, particularly for divers over the age of 50; fatigue; cold water exposure, which can cause the blood vessels at the body's extremities to close down and maintain the body's core temperature; pre-dive exercise, which can create new gas nuclei; exercise during the dive with blood bringing additional nitrogen to muscle tissues; post dive exercise which can cause supersaturated blood to course thorough the blood vessels; tight fitting equipment, which can cause DCI pain around a joint where the limb is pinched by the suit; hot showers or baths and sunbaking can all raise the skin temperature and reduce the capacity of the skin to hold nitrogen in solution; and dehydration, which effects the micro circulation and therefore the out-gassing of nitrogen after diving.

Personal Mode	**Symbol on display**	**Condition**	**Desired tables**
P0	🏊	*Ideal Condition*	*Default*
P1	🏊+	*Some mentioned factors or conditions exist*	*Progressively more conservative*
P2	🏊++	*Several mentioned factors or conditions exist*	

Depth metres	**Personal Mode**		
	P0	**P1**	**P2**
9	--	163	130
12	124	89	67
15	72	57	43
18	52	39	30
21	37	29	23
24	29	24	19
27	23	18	15
30	18	14	12
33	13	11	9
36	11	9	8
39	9	7	6
42	7	6	5
45	6	5	5

CREDITS

Much of the work in developing the Suunto RGBM was pioneered by Dr Bruce Wienke. Dr Wienke is a Program Manager in the Nuclear Weapons Technology Simulation And Computing Office at the Los Alamos National Laboratory (LANL), with interests in computational decompression and models, gas transport, and phase mechanics. He is the developer of the Reduced Gradient Bubble Model (RGBM), a dual phase approach to staging diver ascents over an extended range of diving applications (altitude, nonstop, decompression, multiday, repetitive, multilevel, mixed gas, and saturation).

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